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ABBREVIATIONS.—P = Paper; D = Discussion; I = Illustrated.
Names of authors of papers, etc., are printed in *italics*.

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THE FIRST ENGINEER.

BY W. A. TRUESDELL, MEMBER CIVIL ENGINEERS' SOCIETY OF ST. PAUL.

The University of Alexandria was the glory of ancient times. That remarkable seat of learning was founded in the fourth century B. C., and flourished for a thousand years. When the Christian religion grew to importance the school commenced to decay, and it was finally destroyed by the followers of Mahomet in the year 641 A. D.

Among the teachers and scholars assembled at Alexandria during this long period were many eminent mathematicians, who will be remembered as long as there is history. It was here that Euclid lived and wrote his great work. These men gradually built up the science of geometry, until at about the time of the birth of Christ, they knew as much of that subject and of conics as we do to-day. During two thousand years nothing has been added to the teachings of those old Greeks, because there has been nothing to add. They had found it all.

But while these mathematicians cultivated the science of geometry to perfection, they did it only for the sake of the study itself. They either could not or would not see anything useful or practicable in it. They objected most decidedly to the idea of removing it from the classical domain where they had placed it, and considered it vulgar and degrading to apply it to mensuration, surveying or any other practical purpose. In this they were all alike.

Finally, a very able and distinguished man appeared among

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this group of philosophers, who departed from the accustomed methods of thought, and pursued a new line of study and for an altogether different object; who sought to find what was useful in science and to reduce it to some practical application.

This was Heron or Hero of Alexandria, who lived in that city in the second century before Christ. He was a pioneer in a new field, and his labors and their results are so unlike those of the men who had preceded him and who followed after, that he occupies a position alone and unique in the long list of Alexandrian scholars.

He was a famous character in his time, and his name is famous yet in certain departments of history. As a mathematician he was eminent among giants. In natural philosophy he was far in advance of his time, and was acquainted with facts and principles which moderns have never given the ancients credit for. As an inventor and mechanic he constructed a large number of machines and mechanical devices that have served as prototypes long after, and led to inventions of great practical importance.

The principles of land surveying were original with him. He constructed the first surveying instrument and taught how to use it. It was he who first placed surveying and engineering on a scientific basis.

This old Alexandrian scholar, who lived so long ago, was at once mathematician, mechanic, and inventor, a practical surveyor and engineer. He was the first, of whom there is any record, to labor for a system. He created a science and then brought it to useful and practical applications. For these reasons we will call him the first engineer.

We know very little of Hero's life. It is only from his writings and the works of commentators that we get our knowledge of him. It is supposed that he was an Egyptian, though he was a Greek in training, association, and education. He was the author of quite a large number of books, some of which are now lost, and several of those that are extant consist only of fragments. His principal works have been translated and printed. The originals are now preserved in the leading libraries of Europe.

Among them are three works on machines of ancient warfare, in which are described all the then known implements of that character. One work on automata describes and tells how to make water clocks and water organs, and other self-acting machines. Two others contain what would now be comprised in an elementary book on mechanics and hydrostatics. The best-known book is the *Pneumatica,* which contains descriptions and

illustrations of a large number of machines and mechanical contrivances, many of which were his own invention. Another work, the *Dioptra*, is a treatise on land surveying and leveling, where the first principles of those subjects are made known for the first time. His most characteristic work is a synopsis of elementary geometry and mensuration, where he treats of geometry in a practical manner and gives a great number of rules of application. Besides these works, there were five more on kindred subjects, which are now entirely lost. They were probably destroyed when the Alexandrian library was burned.

In the third century A. D. there was in the Alexandrian school an eminent mathematician named Pappus, who was distinguished as the author of a complete synopsis of Greek mathematics. This work is now preserved, and gives the only knowledge that is now known of the lost writings of the Alexandrian library. Pappus mentions these five lost books of Hero and gives an account of their contents, and in all probability they were as valuable as the works that are now extant.

This list of fourteen books covers the whole range of what was then known of practical mathematics and mechanical philosophy, the result of great labor and research, all written by one man in ancient Egypt, and in the second century B. C. It would be quite correct to say that practical mathematics and mechanical philosophy originated with the author of these books.

Hero was an able mathematician and learned all that the text books of that period could teach him, though he did little or nothing to extend a knowledge of abstract mathematics. He was preeminently a practical man, and was interested in science only on account of its application. If his results were true, he did not care for any theoretical reasoning by which they were obtained. He did not hesitate to add lines to areas or to multiply squares by squares, a proceeding which always raised a storm of objections. What concerned him most about any principle was, what good is it and how can it be used, and his whole life was devoted to teaching people how to use what others had found. If he made any investigation of his own or originated anything new, it was always something important and practical. The early trigonometry, in which chords were used instead of sines, had always been considered a part of astronomy, or an appendage to that science. He was the first to think differently, and to make practical applications. He attempted a solution of that famous old problem, the duplication of the cube, but only for the purpose of showing how a machine of warfare, known as the catapult, could be increased three-fold in

power. He originated new methods in numerical calculations, and used to multiply and divide in a manner which is essentially the same as we do at present. He was the first to give a methodical rule for the extraction of square roots. At that time all numerical calculations were founded on a geometrical interpretation, and no other method was countenanced by the Alexandrian philosophers. Hero persisted in using methods of his own, which, if supplied with a proper symbolism, would have been pure algebra. In his works he gives problems with solutions which require quadratic equations. This is the first record of anyone who could perform such calculations.

In his researches in natural philosophy, Hero was the greatest of all ancient scholars. That subject had received but little attention before his time. He experimented and wrote on the elasticity of air and of steam. He was acquainted with the pressure of fluids, and wrote on hydrostatics and hydraulics. He explained how to find the center of gravity of the different geometrical figures and solids. From what was then known of motion and force, he deduced the five mechanical powers, the lever, wedge, screw, pulley and wheel-and-axle, and called them by names corresponding with those used to-day. He afterwards discussed at length the problem of moving a given weight with a given power, and showed how to unite and combine those mechanical powers in different ways, so as to get the best results. In his books on war engines, he explains the construction and principle of those machines, and gives suggestions how to increase their power and effectiveness.

But Hero's reputation as a practical man is still greater when his achievements as a mechanic and inventor are considered. The best-known and the most interesting of his books is the *Pneumatica*, in which he describes and illustrates over one hundred machines and mechanical contrivances, some of which are exceedingly ingenious. He states that he is the inventor of most of them, but does not specify these. It is probable that, as he constructed them, they were only intended for models to illustrate his experiments and researches.

One of the machines described in the *Pneumatica* was called the Fountain, and is a familiar object to those who remember the old text books on natural philosophy. By this contrivance air is condensed in a chamber by means of a column of water, and the air, in turn, raises another column to a height equal to that of the condensing column. This is the oldest pressure engine known, and it has been imitated in modern times. A machine very much

similar and acting on the same principle was once employed to raise water from a mine in Hungary, where it was long celebrated. By means of a spring 140 feet above the mouth of a shaft, water was raised from the bottom, 104 feet, to the top, and the mine was thus drained.

Another remarkable machine described and illustrated in the *Pneumatica* is a fire engine, invented and constructed by Hero himself. This was founded on the principle of atmospheric pressure, and did not differ in its essential parts from a fire engine of modern construction. It consisted of two brass forcing pumps, each with a valve and piston connected to one discharging pipe. The pistons were worked by a double lever. The two pumps were secured to a wooden base which was partly immersed in water, and the whole arrangement was mounted on a sort of carriage. The discharge pipe, into which the water was pumped, terminated in an air-chamber, and from this chamber the water was forced through another pipe, which could be turned in any direction by means of a swivel joint. The principle of the whole machine, the two pumps, pistons, valves and air-chamber, the outlet and inlet pipes, was the same as employed in engines of like character in modern times.

In the *Pneumatica* we have also an account of the first steam engine ever known. It could not have been of any practical utility, but it was the first instance where motion was produced by steam. This, also, is a familiar object, and has often been described and illustrated. It consisted of a hollow sphere furnished with two arms at right angles to its axis, and bent in opposite directions at the ends. The sphere was suspended between two upright columns, which were bent at their extremities. One of them was hollow, and through it the steam passed from a boiler below to the sphere, and the escape of the vapor through the small tubes produced a rotary motion. The principle employed in this ancient contrivance has been patented in Europe no less than six different times, and that early effort of Hero has been developed into machines of great usefulness. It was a forerunner of the primitive Barker's water mill and the modern turbine.

Another apparatus described deserves mention, because it was the prototype of a class of engines that became long afterward practically important. This was a heat engine, in which expanded air, by means of fire, was made to open and close doors, and was used in temples, theatres and other public buildings. This was the first step toward what is now the modern steam engine. Eighteen hundred years after a machine working on the same principle, but

with steam instead of air, was patented in Europe by Thomas Savary, and was used for pumping water from mines in England and Scotland until the beginning of the present century.

In the *Pneumatica* more than twenty different forms of the siphon are described, or rather that many different methods of using the instrument are illustrated. Hero explains how it can be employed to drain or irrigate land, by conveying water a long distance over hills and valleys. From him we learn that it was extensively used at that time to irrigate lands bordering on the desert.

The *Pneumatica* was much sought after and studied during the sixteenth century by mechanics, engineers and all others engaged in mechanical research. It was a veritable feast to men like Fludd, Porta and Galileo, who made great use of it, the former without any acknowledgment.

Hero's principal and most characteristic work is his practical geometry and mensuration. This was the first effort to use geometry for practical purposes, and was in direct opposition to the teachings of the Alexandrian school. He gives a large number of rules and formulas, usually without proof, for finding the areas of all geometrical figures, from triangles to segments of the circle, also polygons of any number of sides, and fields of different shapes and with irregular outline, and then tells how to find the height of an inaccessible object. Afterwards, rules for finding the volumes of all the different solids, and then shows how they can be made useful in the practice of architecture, such as theatres, halls, baths, etc. The book concludes with a table of weights and measures.

The most interesting to us of all Hero's books is the *Dioptra*, which is, in reality, a treatise on land surveying. It is the first book ever written on that subject, and is a collection of the earliest rules and principles ever used by any surveyor. Hero was, without any doubt, the originator of systematic surveying and leveling.

First, there is a description and illustration of the instrument called the dioptra, which was the original transit or theodolite and level. The greater part of the book consists of thirty-three problems, most of them relating to surveying and leveling, with their solutions by aid of this instrument.

The dioptra, as it is described and illustrated by Hero, was constructed in the following manner: The whole instrument, with the exception of a glass water level, was made of brass, and was about five feet high. The lower part or support was a hollow cylinder about three feet in length, with three sharp prongs at the bottom to hold it firmly to the ground, and a small weight was suspended by a string at one side, to show when it was vertical.

On top of this support a large circular plate was fastened, always in a horizontal position when the instrument was in use. Above this was a second hollow cylinder less than a foot in length, and enveloping a spindle of the same length, which was fastened to the large circular plate. The bottom of this second cylinder was a cog-wheel, of a diameter less than that of the circular plate on which it rested, and the top, by way of ornament, was finished off like a Doric column, with a square capital on top. A long screw was fastened to the circular plate by two pins and tangent to the

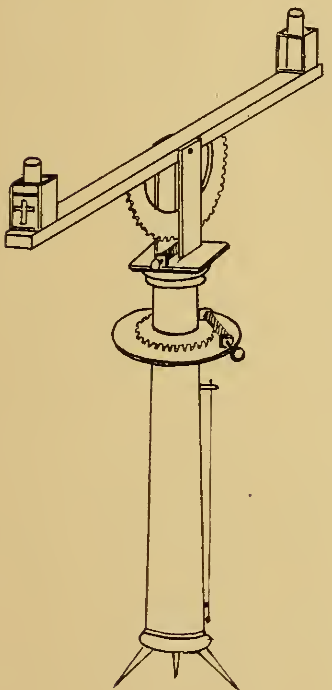


FIG. 1.

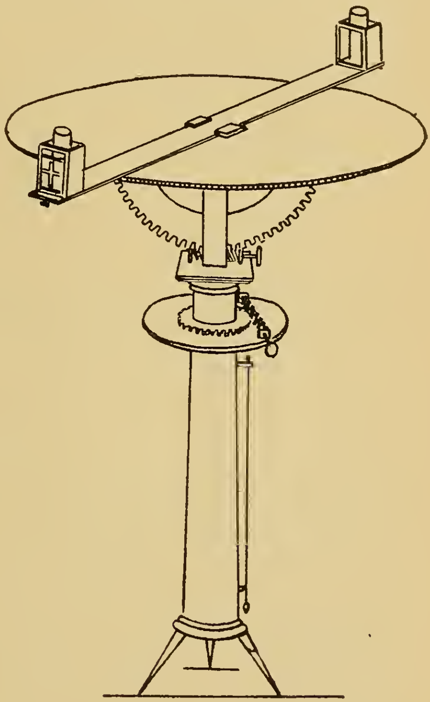


FIG. 2.

cog-wheel. By turning this screw all of the instrument above the circular plate could be revolved in a horizontal direction around the stationary spindle. Above the square capital were two vertical blades or standards, about a foot long, and between them, at the

Fig. 1 represents the dioptra as it is described and illustrated by Hero, but some of the problems which he gives required an instrument of somewhat different construction. These are Problems 16, 17 and 28. In the original manuscript there is a blank space, which is supposed to have been meant for another illustration. Fig. 2 is this illustration, as restored by Venturi, an Italian commentator.

top, was a rule or straight edge, six feet in length, and hung to them by a pin or journal, to allow a movement of the straightedge in a vertical plane. Below the straightedge, and between the standards, was a vertical semi-circle, cogged at its outer edges and turned by a long screw fastened to the square capital. On top of the straightedge a long water level was placed, and at each end was a thin blade with a slit cut in it, through which the observer could look.

The dioptra could be used for staking out straight lines or for leveling. To lay off a right angle, two little points or marks on the large circular plate were used. The upper cylinder was placed first at one of these marks, and a line was set on the ground. The cylinder was then turned to the other mark by the lower tangent screw, and thus gave a line at right angles to the first. For leveling, it was only necessary to bring the straightedge to a horizontal position by the upper tangent screw.

Hero also describes what he calls two poles, which were used with the dioptra, either as leveling rods or as pickets; that is, one for a foresight and the other for a backsight. Each of these poles was about fifteen feet long, four inches wide, and two and one-half inches thick. In the middle of one side, and for the whole length, a dove-tailed groove was cut, and in this a tenon was placed so as to move easily. On this tenon a circular target, nine inches in diameter, was fastened, one-half painted white, the other half black. A cord tied to the target ran over a grooved wheel at the top of the rod, and could be tied to a pin on the back of the rod. The target was raised by this cord and lowered by its own weight. The rod was divided into cubits, palms and digits, commencing at the bottom. To hold the rod in a vertical position, a small weight was suspended by a cord from the end of a short pin at the top.

The dioptra was the only surveying instrument known for a very long period. It was introduced into Rome, where it was extensively used by the Roman surveyors for at least five or six centuries, both as a transit and as a level. While the Empire was at the zenith of its power, the Romans carried on quite a large system of improvements. They were great surveyors, great map makers, and, in a practical way, great engineers. In the construction of their military roads, arch bridges, harbor improvements and extensive aqueducts, all the necessary instrument work was done with the dioptra in the same manner that Hero had taught.

The circular plate on the dioptra was not divided into degrees, and only right angles could be measured with it. It does not appear that the graduated circle was ever used in ancient times.

For measuring angles at that time the cross staff was used. This was seldom required, and then mostly for astronomical purposes. It is probable that in surveying, angles were determined by chords. In the latter part of the fifteenth century, when trigonometry had become something of a science, one quadrant of the circle was divided into degrees, and some years later the opposite quadrant was graduated, to give the benefit of a second reading. About one hundred and fifty years after this, or in 1631, the vernier was invented and added to the instrument. It was only about one hundred and thirty years ago that the whole circle was graduated for the first time.

The following problems are all contained in the *Dioptra*. Each solution is written out at length, and every operation is explained in detail in Hero's book. A very brief outline only of these solutions is given here. The figures are exact copies of the originals, except the lettering:

(1) *To find the difference of level between two points.*

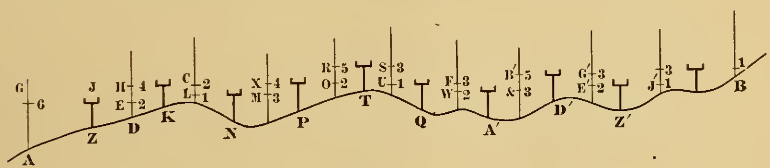


FIG. 3.

The solution of this problem is similar to those given in modern text books. A supposed case is illustrated, and the author gives very minute directions about placing the dioptra and lèveling rods at each successive stage of the operation.

The backsights he enters in a column marked "down," and the foresights in one marked "up," and after adding the two columns he takes the lesser sum from the greater for the difference of level. He concludes with some remarks about the usefulness of this process in conducting water from any place to a lower one, and around intervening elevations and depressions.

(2) *To run a line from a given point to a second point which cannot be seen from the first.* (Fig. 4, page 10.)

Hero's solution of this problem makes a modern surveyor think of latitude and departure. His process is, in reality, an application of that method.

Let A and B be the two given points. Connect them with the dioptra by several different lines, making each line of any convenient length, and at right angles to the one preceding it. Write the lengths and add them as follows:

	A G = 20 cubits.		G D = 22
	D E = 16 "		E Z = 30
—	Z H = 14 "		H C = 12
	C K = 60 "		K L = 8
—	L B = 50 "		—
	—		72
	32 "		

This gives A M = 72 cubits and M B = 32 cubits. Measure on A M any distance A T = 9, and make 72 : 32 : : 9 : T U = 4. Also measure U F any distance, say 18 cubits, and make 72 : 32 : : 18 : F Q = 8. Continue this operation and get U, Q, etc., points on the required line.

(3) *To measure the horizontal distance to an elevated distant point without approaching it.* (Fig. 5.)

Let B be the distant point. With the dioptra at A, mark the point G and lay off the perpendicular A D, also G E of any con-

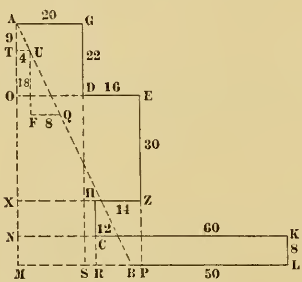


FIG. 4.

FIG. 5.

venient length. With the instrument at E, mark the point D on line with B, and measure A D and A G.

Then the required distance A B will be that part of B G that A D is of E G. It will then be known what part A G is of B G or of A B, and the latter line can be easily determined.

(4) *To find with the dioptra the width of a river, remaining on one and the same side.*

This problem is merely a continuation of, ro an application of, the preceding one. It was long afterwards a favorite with the military engineers attached to the Roman armies, and was called by them a problem in strategy.

(5) *To measure the horizontal distance between two distant inaccessible points.*

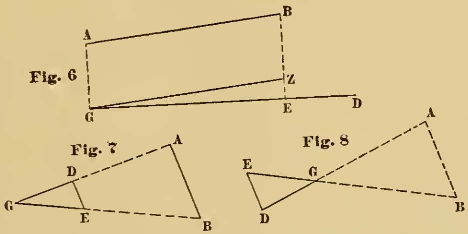
First solution. Fig. 6. Let A and B be the two given points. From any assumed point G, lay off G D at right angles to A G.

Set the dioptra at E so that E B will be perpendicular to G D, and by problem 3 find A G and E B. Measure the difference of these distances E Z on E B. Then G Z will be parallel and equal to A B, and can be measured on the ground.

Second and third solutions. Figs. 7 and 8. From the assumed point G, calculate A G and G B by problem 3. Lay off G D equal to one-tenth of A G, and G E equal to one-tenth of G B. Measure D E, which will be one-tenth of A B.

(*6*) *To lay off on the ground a perpendicular to an inaccessible line at one of its extremities.* (Fig. 9.)

Let A be one extremity of an inaccessible line A B. Hero's solution of this problem is to lay off a line G D parallel to A B by problem 5, and then by trial to find the point E, so that a perpendicular E A to G D will pass through the point A.



FIGS. 6, 7, 8.

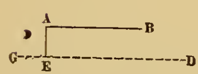


FIG. 9.

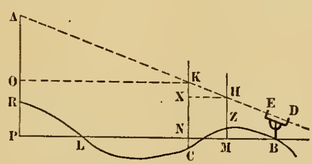


FIG. 10.

(*7*) *To measure the vertical height of an inaccessible point.* (Fig. 10.)

Let A be the elevated point, B Z C L R the surface of the ground, and B P the plane of the horizon at the point of observation B. Calculate the horizontal distance B P by problem 3. Set two pickets H Z and K C so that their tops are in line with A. By leveling, find Z M and N C. Then we will have H M and K N. Measure H X, and K O will be known. By similar triangles A O is found, and this added to K N gives A P the height required.

(*8*) *To measure the difference of heights of two inaccessible points.*

(*9*) *To measure their distance apart.*

(*10*) *To determine the position of a line which joins them.*

(*11*) *As an application, to measure the height of a mountain.*

The solutions of these four problems are merely a continuation and application of the preceding ones, especially of problems 3, 5 and 7. Problem 11 consists of remarks and directions about measuring and locating the different points on a mountain.

(*12*) *To measure the vertical depth of an excavation.* (Fig. 11.)

Let A D O be the horizontal plane. With the dioptra at E, set two rods K N and X M with their tops on line with the point B at the bottom of the excavation. Measure A O by preceding methods, also K M, and by leveling K S and M O. By the two similar triangles X N R and X B P, X P can be found, and as X O is known, O P or its equal A B is known, which is the vertical distance required.

(*13*) *To cut a tunnel through a mountain from one given point to another.* (Fig. 13.)

Let A B G D be the base of the mountain, and B and D the two points. Run the lines B E, E Z, Z H, etc., each one at right

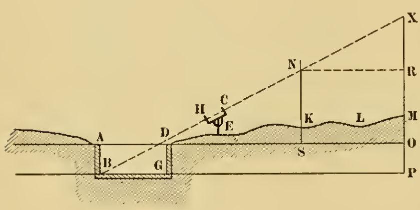


FIG 11.

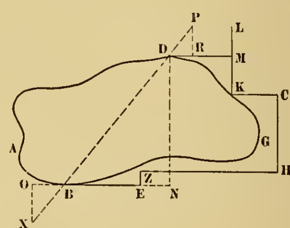


FIG. 12.

angles to the one which precedes it, to K L. On K L find the point M, so that a perpendicular to K L will pass through D. Find B N and N D the same as in problem 2. Lay off O B X and D P R each similar to B N D. X B will give the direction at the portal B, and P D at the portal D. The author adds that "to insure the success of the operation, it will be necessary to plant a picket at some point in X B and P D produced, so that the workmen will finish by meeting each other."

(*14*) *To sink vertical shafts to meet a horizontal tunnel.* (Fig. 13.)

G A B D is the line of the tunnel; the portals at A and B. Place the instrument at H on line with two pickets at G and A. Move the picket at G, and place it on line at M. Then carry the dioptra to X on line with the pickets at A and M. Move the picket at A and place it on line at O, and so on. This will give points like M and O for shafts, directly over the tunnel.

The author says, in addition, "that for correctness, these points should also be established from the line B D."

Problem 15. *Having given a crooked subterranean gallery, to find on the ground above a point from which to sink a shaft to a given point in the gallery.* "So that material for construction may be lowered, and the debris removed in case a crumbling place is reached." (Fig. 14.)

In the given solution two shafts are already excavated. A B D G E is the gallery, and M the required point. A plumb line is lowered in each shaft and the two points P and X marked on the floor of the gallery. On the line P X S a series of triangles are measured off, so that a side of the last one will pass through the point M. These triangles are then laid off on the ground above and the point V is located, from which a shaft would reach the given point M.

Problem 16. This consists of directions, showing how to locate and draw the shore lines of a river or harbor. Problem 17 explains how to throw up or grade any given area of ground in the form of a spherical surface, and Problem 18 how to grade or slope a piece of ground of any shape to a given inclination.

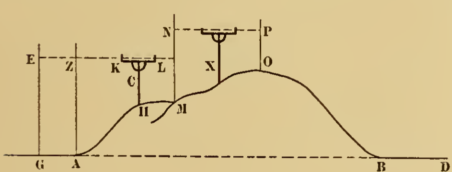


FIG. 13.

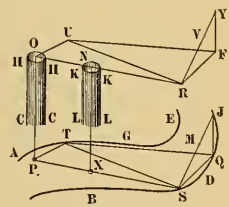


FIG. 14.

(19) To measure in a given direction any given distance. (Fig. 15.)

This problem reminds one of stadia surveying. The dioptra is set up on a level piece of ground, with a vertical rod a short distance away. Opposite to the rod, distances are measured off on the ground. Marks are now made on the rod where lines of sight strike it, which pass from the points on the ground through both eye-pieces of the dioptra. In this manner the rod is graduated, and may be used with the dioptra to lay off any length, or to measure to an inaccessible object, always placing the rod the same distance from the dioptra that it was when graduated.

(20) From a distant inaccessible point, to lay off a given distance in a given direction. (Fig. 16.)

A is the given point, B the dioptra. Find A B according to problem 3. On A B take B G, which may be any part of it. Lay off D G parallel to the given direction by problem 5, and make it the same part of the given distance that B G is of A B. Produce

B D and make B E the same multiple of B D that A B is of B G. A E will be the required line.

(21) *To measure the area of a field of irregular shape.* (Fig. 17.)

In the field a rectangle is laid out, having three of its corners in the irregular boundary. From the sides of the rectangle offsets or ordinates are taken to the boundary, at certain intervals or whenever necessary, and dividing into triangles and trapezoids the field outside of the first rectangle. From these data the area is calculated by finding the sum of all the interior figures.

A second solution is given where the boundary is made up of straight lines. The field is divided into triangles and trapezoids.

(22) *To restore lost corners of a field.* (Fig. 18.)

A field with an irregular boundary is given. In the first

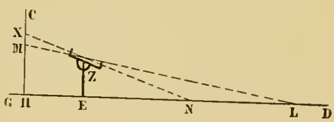


FIG. 15.

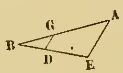


FIG. 16.

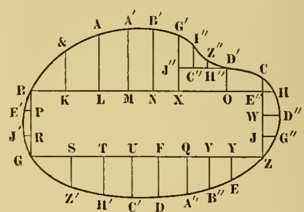


FIG. 17.

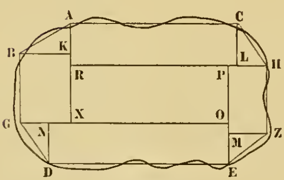


FIG. 18.

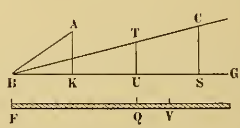


FIG. 19.

place, to represent on paper a plan of this field. The irregular boundary is determined by straight lines, drawn so that those marking the ends of the field will be at right angles to those which determine the sides. The interior is then divided into triangles and rectangles. The lengths of all the sides of the interior figures are measured and marked on the plan. In a field, represented by the above figure, all the boundaries except the points B and C are gone. It is required to restore the lost corners on the ground, for example, the one at A. (Fig. 19.)

Measure in the field a line from B to C. B G is supposed to be parallel to the longitudinal lines of the field, though not yet determined on the ground. Take B T any part of B C and in the

triangles B T U and B C S, B S and C S are known from the plan, and B U and T U can be calculated by proportion. Mark on a chain F Q equal to B U, and Q V equal to T U, and with the end F at B and V at T, stretch the chain and Q will give the point U, which will locate the line B G on the ground. On B G lay off B K according to the plan, and erect K A perpendicular to B K. This will re-establish the corner A. This is as far as the solution goes, but it concludes with the remark that all the other corners can be restored by processes similar to the one here explained.

(*23*) *To divide a field into given portions by lines starting from the same point.* "Suppose, for example, that the given point is a reservoir of water, which all the owners of the field are to use." (Fig. 20.)

Calculate the area of the whole field. It is required to divide it into seven equal parts by lines starting from M. Take the triangle A M B and find its area. If more than one-seventh of the whole field, find the triangle B M X equal to the surplus, and

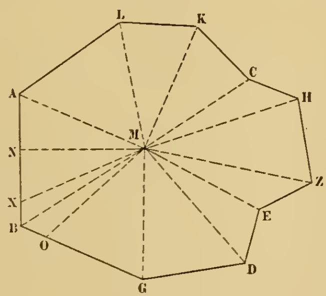


FIG. 20.

then A M X will be the first required part. If A M B is less than one-seventh, find B M O equal to the deficiency, and then A M O is the first seventh part. In the triangle B M X, to find B X we have the area and the altitude M N, from which B X is easily found. Operating in the same manner on the other triangles, the whole field will be divided into seven equal portions.

(*24*) *To measure a field without entering it*, "by reason of thick vegetation or because it is not permitted to enter it." (Fig. 21.)

A B G D, etc., is a given field. Prolong C H to L and Z H to K, so that H K is the same part of H Z that H L is of H C. Then from K L we can find C Z, and from the triangles K H L the triangle C H Z can be found. K L is parallel to C Z. C may not be visible from Z. Prolong H Z and make Z M equal to H K. With a chain equal to K L plus L H, and with its ends at Z and M, mark the point N on the ground. This will give C Z produced.

Prolong E Z to X, so that Z X is any part of E Z, and make Z O the same part of C Z. This will give Z X O a triangle similar to C Z E, and the area of C Z E can be obtained. In the same manner calculate the areas of the remaining triangles, from which the area of the whole field can be found.

(25) *To divide a trapezoid by a line parallel to its base.*

The inclined sides of the trapezoid are produced to an intersection, and the similar triangles so formed gives, by proportion, the length of the required dividing line and its position.

The method of finding the area of a triangle from the three sides was original with Hero. He gives an ingenious proof, and works out an example where the sides are 13, 14 and 15. This is problem 26 of the *Dioptra.*

(27) *To measure the quantity of water flowing from a spring.*

"In times of rain the flow augments, caused by the super-

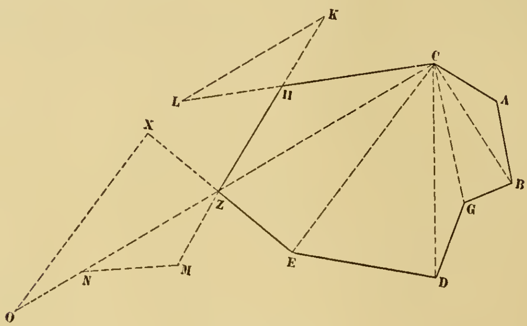


FIG. 21.

abundance of water which comes from the mountains, and spouts up with great force. It diminishes, on the contrary, in times of drought, because enough water does not reach it to feed it. Make a conduit in the form of a quadrangle, then adapt it to the spring in such a way that all the water is forced to enter it. Take, then, at the end of the conduit the water which runs out. Suppose it is two digits high and the width six digits. This will give a section of flow of twelve digits." Then, by ascertaining the velocity of the current with a sun dial, the amount of flow in an hour can be determined. A better method, the author adds, is to dig a reservoir and let the water run into it for one hour and then measure the amount of water.

(28) *To measure the angular distance between two fixed stars.*

This requires an instrument somewhat different from the one described by Hero. There is a large circular plate on which the

rule revolves. The outer edge of the plate is divided into 360 degrees, and the rule is capable of being removed entirely from the plate. After removing the rule bring the plane of the plate in the line of the two stars and clamp it. Replace the rule and direct the sights to one of the stars, and by means of a pointed index on the rule note the reading on the circle. Turn the sights to the other star and note the reading. This will give the number of degrees between the two stars. Whether this was really ever accomplished or is merely a suggestion does not appear. At any rate, it is the first mention made of a circle being graduated into 360 degrees.

(*29*) This problem is a criticism on the asterisk, an instrument in use at that time to a limited extent. Hero attempts to show the superiority of his dioptra, as constructed by himself, over the asterisk for practical use.

(*30*) This is a long description of a contrivance called an odometer. It comprised a series of cog-wheels attached to a carriage, and so arranged as to move a pointer on a measured dial, and thus indicate the distance traveled. There is an illustration also given.

(*31*) *To ascertain the speed of a ship.*

Another odometer, consisting of four cog-wheels, is illustrated and described. A paddle-wheel is secured to the side of a ship, and the motion of the vessel through the water causes the wheel to revolve. The wheel, in turn, moves the cog-wheels, and a pointer on a dial indicates the distance the vessel travels.

(32) To determine the distance between two places on the earth's surface, as, for example, from Alexandria to Rome, "following the circumference of one of the great circles."

Hero works out this problem substantially as follows: The circles of a celestial sphere are drawn, with a latitude equal to that of Alexandria. By means of an eclipse of the moon, he determines the difference of longitude. This, he says, can be taken from the "Register" or can be determined by observation. This difference of longitude locates the meridian of Rome on the sphere, and the latitude of that city, which he determines, locates the zenith of the horizon at Rome. A great circle is then drawn through this point and the zenith of Alexandria. The angular distance between these two points he determines mechanically and finds it to be 20 degrees. About one hundred and fifty years previously, Eratosthenes had found the circumference of the earth to be 252,000 stadia, or 700 stadia for one degree. Hero says the required distance is 14,000 stadia.

2

(33) *With a given power, to move a given weight by means of a system of cog-wheels.*

It is explained and illustrated in the solution of this problem how to construct four cog-wheels, turned by a crank, so that one man, exerting a power of five talents, can lift a weight of a thousand talents.

In these problems, Hero made no use of trigonometry. That science had been invented just before his time, and at first there was very little of it. There was in existence a single table of chords, by which both plane and spherical triangles could be calculated. But this was considered an inseparable part of astronomy, and even in that science very little use was made of it. Sines, co-sines and tangents were not invented until a thousand years later. Hero, however, was the first to perceive the utility of trigonometry and to make a practical use of it. By means of it, he calculated rules for finding the areas of regular polygons of from five to twelve sides, and these are the rules which can be found to-day in any text book in mensuration.

Hero was the first to place the art of surveying on a correct foundation. He was a scholar, an investigator and a teacher. He was the originator of practical mathematics. He was the first engineer, in the same sense that Thales was the first geometrician, Hipparchus the first astronomer, or Galen the first physician. He collected all the isolated facts and fragments then known relating to his special subject, added to them by his own researches and endeavored to bring them together in one comprehensive body, for it is now conceded by competent authority that all his books, now in disconnected fragments, were originally one complete work containing all the knowledge necessary for surveyors, mechanics and architects in the practice of their vocations.

The works of Hero, owing to their practical character, were much sought after and were extensively used by the people of the surrounding nations. Like all other works from the Alexandrian school, they were known in India and Arabia, but the greatest field for their usefulness was among the Romans. Hero's practical geometry and surveying comprised all the mathematics ever known in the Roman Empire. Hero was a teacher of the Romans. They afterwards elaborated his methods of surveying, and in time carried that art to great excellence. They cared nothing for the abstract geometry of the Greeks. They were no investigators, and in all Roman history there is no mention of a mathematician of any note whatever.

In the special line of work in which Hero was distinguished

no one followed him to complete what he began. His successors in scientific ability fell back either on astronomy or the well-worn subject of geometry. The Alexandrian school continued to exist for eight hundred years longer. On its destruction, in 641 A. D., the Greek scholars who were then living there fled to Constantinople, and carried with them what books they could save from the wreck of the library, which the early Christians had ruined, and which the Arabs finally destroyed.

A very long time after this, or in 1453, the Turks besieged and captured Constantinople. The Greek scholars who escaped the slaughter fled to Italy and carried with them the remnants of the Alexandrian library, which had been preserved in Constantinople for eight hundred years, and for the first time the people of Europe came into possession of the remains of that storehouse of learning which had been built up in Alexandria many centuries before.

HIGH GRADE STEEL.

By J. C. Danziger, Member Detroit Engineering Society.

[Read before the Society, June 19, 1896.*]

PROCESSES OF STEEL MANUFACTURE.

The leading processes by which steel is made are, in the order of their importance, (1) the Open Hearth, (2) the Bessemer, and (3) the Crucible; or, in chronological order, (1) the Crucible, (2) the Bessemer, and (3) the Open Hearth. Several conditions are tending daily to increase the importance of the Open Hearth process. By this process phosphoric ores may be successfully handled and ingots of the largest size produced. It enjoys more of the confidence of engineers than does the Bessemer, and its product is cheaper than crucible steel.

Briefly reviewed, these processes are as follows:

In the Bessemer process the molten iron is poured into the converter, which is a pear-shaped vessel, lined with a basic or an acid refractory lining, as the process is to be basic or acid. The carbon and silicon of the bath are, as far as possible, burned out by a blast of air through the iron, and the bath is then recarburized to the required amount with molten pig or spiegel. If with the former, ferromanganese is added to furnish manganese to the bath and to combine with the sulphur and the superfluous oxygen, and the steel is then ready for the moulds.

In the Open Hearth process, the pig is melted down in a reverberatory furnace, either basic or acid lined, and the carbon and silicon are removed by adding a pure oxide of iron (ore) to the bath. The reduction is carried only to the desired point, and no effort is made to burn out all the carbon with a view to recarburizing, as in the Bessemer process. Ferromanganese is generally used to impart manganese and carbon to the bath.

Oxide of nickel, ferro-silicon, etc., are also used in certain cases to obtain special results. The metal is then ready for the mould. The points of difference between these two processes are: the much longer time occupied by the Open Hearth, the larger charges, perfect control, and the frequent analyses.

The Crucible process is of minor importance, the steel being used only for cutlery, files, saws, and other tools. There is little doubt that much of this ware, stamped "Warranted Cast Steel," or,

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"Warranted Crucible Steel," is in reality made of select Open Hearth, or even Bessemer, and is perhaps the better for it.

Bessemer steel is looked upon with not a little disfavor at present, for higher grade purposes. Many engineers consider it too unreliable and irregular to be used in construction, where there is any close estimating for strength. This feeling is not without good foundation, but the usual method of manufacture is responsible for it, and not the principle upon which the process is based. The modern high speed of production results in many irregularities, which, with care, could be avoided. The Open Hearth bath is always melted down from select pig-iron, but the Bessemer converter must be content with the direct metal, drawn off from the blast furnace or mixer, dumped in and blown without the composition of the iron being under certain control. Of course there is an effort to keep the furnace on an iron of a certain silicon, also to control the sulphur, but this is not always possible. There is no reason, except the additional expense, why the blast furnace metal should not first be cast into pigs, analyzed, graded, charged into a cupola furnace and remelted before going to the converter, and this indeed is sometimes done in making certain high-grade steel rails.

The length of the blow has also been much reduced. Formerly, if fifteen minutes were used to blow a seven-ton charge, it was thought good practice. Iron of two per cent. silicon was charged, necessitating a blow of that length. The more modern way is to make the blow in from eight to ten minutes. This necessitates rapid blowing, in order that the 1 to 1¼ per cent. silicon may furnish fuel enough to keep up the heat. This rapid blowing, combined with the imperfect control of the composition of the bath, resulting from the use of direct metal, causes the too frequent occurrence of heats which are either too hot or too cold. I do not doubt that, with the proper care, the Bessemer process can be made to yield a medium steel in every way as good as that produced by the Open Hearth.

The Open Hearth process is the only one to use when very large ingots are to be produced. At Bethlehem, and probably at Homestead, ingots are made of upwards of eighty tons weight. On account of the perfect control, the ample time and the frequent analyses, steel of any composition can be produced. All the various steel alloys of iron, with the other members of the iron group, are best produced in this way.

In conversing with some engineers, especially in the West, the writer has found a lurking prejudice against steel. The cause is not far to seek. Wrought iron will submit to all kinds of abuse

of work and heat treatment and show no bad effects. Steel, however, quickly resents the bad handling of ignorant operators. Iron, with its low elastic limit and loosely welded mass, remains, with some, the favorite material, simply because the finer metal is begrudged proper handling.

PHYSICAL PROPERTIES.

The physical properties of steel may be varied by the chemical composition, by the fabrication under hammer, press, or rolls, and finally by the subsequent heat treatment.

The points usually noted in the physical test of steel are: tensile strength, elastic limit, extension, contraction of area, and fracture. To these, for some purposes, is also added the modulus of elasticity. Users of structural steel have long demanded definite qualities in their specifications, but users of steel forgings, which should be of much finer and higher grade steel, are only beginning to ask for definite qualities. The writer has frequently noted the growth of these specifications. Consumers begin by asking for a definite tensile strength. In their next specifications they add extension. Elastic limit is the next addition, and, finally, contraction. In the gun work for the U. S. Army, the elastic limit and extension are considered the most vital points, and, after them, the contraction of area. The tensile strength is considered of less importance. The modulus of elasticity of every test specimen is obtained. This is certainly rational, as, for most purposes, a material is useless after being strained beyond the elastic limit and permanently distorted. The contraction of area is a much neglected qualification, yet there is good reason to believe that it bears a direct relation to the shock-resisting power of steel. Frequently a steel of excellent extension, but low contraction, shows a coarse grained fracture and a rough skin after breaking; but invariably a heavy contraction, even when accompanied by little extension, is associated with a silky grain, or a fracture of minute facets, like points of pins.

The endurance of steel under the drop, and under alternate transverse tension and compression, is of the first importance, but the ordinary tests are so much more readily made, that, except for special purposes, the others are never required. The drop test is made the chief test for certain work, but the test of endurance under alternate strains, or the fatigue test, consumes so much time that it is at present impossible to use it commercially. The only practical course would be to determine, by a series of tests, exactly what relation the endurance bears to the ordinary physical properties, and to base specifications upon these results.

THE EFFECT OF CHEMICAL COMPOSITION.

We have next to consider the effects of the various chemical elements upon the physical qualities of steel. Carbon is, of course, the first to be considered, and its effect upon steel is the best known. Every user of steel has studied the varying effects of carbon, and is more or less acquainted with them. Many attempts have been made to construct formulæ and scales showing the effect of increments of one-hundredth of one per cent. of this element on the tensile strength, but these have met with little success. The weight of evidence indicates that the carbon and tensile strength curve is a straight line, but what its exact equation is, and how it is affected by the presence of the other elements, is hard to determine definitely. The view that the tensile strength is increased by eight hundred to one thousand pounds per square inch by the addition of one-hundredth of one per cent. of carbon, has received considerable support, and is probably very near the right figure. All such calculations must be based upon the tensile strength of absolutely pure iron. This has never been definitely determined. It is well known that carbon gives to steel its peculiar properties of hardening and annealing under heat treatment.

The study of the exact variation of structure which brings about this change is now attracting much attention. The physical conditions are studied microscopically, as follows. A section of steel is carefully ground with emery of the various grades, down to the finest, then with crocus, and finally with the best washed rouge. The surface is then etched with dilute hydrochloric acid and examined or photographed under a microscope, enlarging from thirty to two hundred diameters. Märtens, Sorby, Osmund and Wedding, in Europe, and Howe, Dudley and Sauveur in this country have done much good work in this direction. Steel of all percentages of carbon, and in all physical conditions, has been examined, but nothing positive has as yet been determined.

This much, however, is certain; that there are three constituents that go to make up steel. These are called by various names, but the nomenclature of Howe is generally accepted in this country. He calls them Ferrite, Pearlyte, and Cementite. The first is free, pure iron; the second is of disputed composition, and the third is unquestionably rich in carbon and perhaps a definite carbide.

It is the variation of these three substances that produces the varying physical properties under different work and heat treatment. The effect of carbon is, in a general way, to raise the tensile strength and the elastic limit, to lower the extension and the

contraction, and to change the fracture from silky to dull gray or crystalline. It probably has little, if any, effect upon the modulus of elasticity. In the examination of nearly 20,000 specimens of steel, under every variety of treatment and composition, all turned and polished bars with screw ends, and fully 5000 of these for modulus, with electric contact micrometers, the writer has never noticed that varying the percentage of carbon has any effect upon the modulus of elasticity.

Manganese is next in importance to carbon in controlling the physical qualities of steel. It is primarily added to both the Bessemer and the Open Hearth baths to combine with the sulphur and oxygen, so that these objectionable elements may be drawn off in the slag. Undoubtedly, manganese has, of itself, a counter-effect to sulphur and its presence reduces the red-short effect of that element. Manganese tends to lessen the blow-holes, and its presence results in a sounder casting. The presence of manganese undoubtedly raises the tensile strength and the elastic limit of steel, but it is a question whether it does so by negativing the sulphur and lessening the blow-holes, or, whether it is, of itself, a hardener. It is generally assumed that manganese does harden steel, but its effect varies with the percentage of carbon present, and has about one-third the effect of an equal percentage of carbon. Proportionally, manganese raises the elastic limit much more than it does the tensile strength. The following specimens were cut from one inch rolled bars and annealed at 1000° Fahr., in order to bring them all into about the same physical condition. They were then turned accurately to a shaft $\frac{1}{4}$ square inch in area with enlarged screw ends. The elastic limit was determined with an electric contact micrometer. Unless otherwise noted, the experiments were made by the writer.

	Carbon.	Manganese.	Phosphorus.	Sulphur.	Silicon.	Tensile Strength.	Elastic Limit.	Extension.	Contraction.
(1)	.499	1 25	.059	.090	.279	126,000	73,000	15.25%	41.05%
(2)	.585	.58	053	.089	.117	106,000	56,000	15.25%	31.42%

It will be noticed that the percentages of phosphorus and of sulphur are practically the same in both cases. The carbon in (2), is almost one-tenth of one per cent. higher than in (1), yet (1) has 20,000 pounds (about 20 per cent.) more tensile strength, 17,000 pounds (about 30 per cent.) more elastic limit, 30 per cent. more contraction of area, and a fracture of much finer grain. There

seems to be no explanation of this, except that it is due to higher manganese and silicon, or to some combination of the two. It is of interest to note here that these elements are looked upon with disfavor by some engineers. The higher elastic limit relatively to the tensile strength, accompanied, as it usually is, with a greater contraction relatively to the extension, indicates that this steel is well adapted to resisting shock.

When the quantity of manganese is between 3 per cent. and 5 per cent., it is very hurtful to steel, but when it reaches 7 per cent. to 20 per cent. there results an entirely new and curious steel, called "manganese steel." It is not within the scope of this paper to say much of this alloy, but it is so hard that no tool can machine it, so ductile that it will stretch 25 per cent. or more in 8 inches. With a tensile strength of 140,000 pounds, its elastic limit is only about 60,000 pounds, and the modulus of elasticity is but about 85 per cent. of that of carbon steel. It can neither be softened nor hardened by heat treatment, so that its usefulness is confined to castings which are finished by grinding. This steel is almost unbreakable under the drop, and is astonishingly stiff under the blows. A water-toughened specimen is said by Hadfield to have stretched 50 per cent. in 8 inches, with a tensile strength of 145,000 pounds. Car wheels and other steel castings are being made in this country of manganese steel by the Taylor Iron and Steel Company.

The exact effect of silicon is disputed, but probably it has little, if any, hardening effect. Its presence undoubtedly results in a sounder ingot and consequently in a more highly finished product. Silicon has been said to cause red-shortness, but this is surely not the case. Steels of 0.50 per cent. silicon have been rolled into good rails, so that if this high-silicon steel could be rolled at all the ordinary high percentages cannot cause red-shortness. In recent years there has been a tendency toward the use of higher percentages of silicon. High-silicon steel has been recommended by European ordnance boards for gun-barrels, and silicon seems to improve the wearing qualities of rails.

Sulphur is notable chiefly for its well-known effect in making steel red-short. It has also a slight hardening effect.

The only consideration given to this element is the effort to keep it at a minimum. This is done by the selection of pure, low-sulphur ore, pig iron and coal. Iron will absorb sulphur from any source with which it may be brought in contact. It is desulphurized by the use of manganese, as noted above. Steel from eastern mills usually contains from 0.03 to 0.06 per cent. of sulphur.

That from western mills sometimes contains 0.10 and 0.12 per cent. English rails have been known to have even 0.2 per cent., but such stock could be rolled only at an intolerably high temperature. The allowable percentage of sulphur depends much on the amount of manganese present. Sulphur is so troublesome to the steelmaker himself, that he needs little urging from the user to induce him to keep it at a minimum.

Prior to the introduction of the basic process the presence of phosphorus rendered much ore unfit for steel making. It necessitates the greatest care in making steel by the acid process. Iron will not dephosphorize on an acid lining, so there must be a minimum of that element in the original ore and pig; but muck bar used in the Open Hearth process may first have the phosphorus reduced in a puddle furnace before coming to the steel bath.

Whatever effect phosphorus may have on steel under slowly applied loads, there is no doubt that it makes it extremely brittle under shock. The effect of phosphorus on steel varies with the percentage of carbon, being more harmful with steel of high carbons. Great care should be taken to specify a limit to the permissible phosphorus, for its presence does not prevent forging and rolling, even when unusually high, and it may have no great effect on the ordinary physical tensile test, and yet it may be fatal to the integrity of the steel under shock.

Nickel is an element only recently introduced into steel making. Its use has resulted in steels of the most remarkable properties and of the widest interest to steel users. Expense is the only bar against its universal use for all purposes. The writer has tested nickel steel bars ranging from 2 per cent. to 27 per cent. of nickel. The lower percentages raise the tensile strength, elastic limit, extension and contraction, and largely increase the ratio of elastic limit to tensile strength and of contraction to extension. It makes the grain finer and the steel tougher. Bars cut from a seventeen inch nickel steel, hollow forged, oil tempered shaft for the United States Navy gave results as follows: tensile strength from 90,000 to 94,000, elastic limit from 56,000 to 60,000, extension 26 to 28 per cent., contraction 59 to 61 per cent. With an elastic limit equal to that of gun steel, is combined an extension equal to that of the softest metal. It also gives to steel a quality that has necessitated the use of a new word, non-fissibility. A nicked bar of 27 per cent. nickel may be bent double without breaking beyond the nick. The life of the metal under alternating tension and compression is also greatly increased. The following is from private notes: Rolled bar nickel steel 5½ per cent. nickel, hardened and

annealed. Tensile strength 127,000, *elastic limit 117,000*, extension 21 per cent., contraction 61 per cent. This, I think, will interest every steel user. Also the following: nickel 27 per cent., tensile strength 100,000, elastic limit 47,000, *extension 47 per cent.*, contraction 61 per cent. This shows a pretty wide variation of qualities with the different percentages of nickel. The 27 per cent. nickel steel will not rust even in salt water, and may be bent, after nicking, without breaking, but 27 per cent. is beyond the point where nickel increases the tensile strength. As may be seen, the 27 per cent. steel is much lower than the 5½ per cent. steel in this respect, although higher in extension.

Besides the foregoing elements, chromium, tungsten and aluminum are used in the manufacture of steel. Chromium, to make the well-known "chrome steel," used for armor-piercing projectiles and burglar-proof safe plates and jail bars. "Mushet's Special" is a tungsten steel well known in this country. Aluminum is used in Mitis steel castings. Copper steel has been tried and has shown some remarkable properties, but has never gone beyond the experimental stage. The tests showed a high elastic limit, but the steel was unsound.

SEGREGATION.

During the cooling of an ingot, some of the elements separate from the mass and consolidate toward the top of the ingot. Phosphorus shows the highest proportional segregation, and sulphur the next. Carbon segregates more than any other element, because it is present in such excess over the others. Silicon and manganese segregate very little. The segregation is in proportion to the time of cooling, and, therefore, generally proportional to the size of the ingot. The segregation of phosphorus and sulphur is often so great as to make their percentage, at the top of the ingot, dangerous where otherwise it would be harmless. Herein lies one of the dangers of making a forging from an ingot but little heavier than the finished work is to be. It is often advisable to discard 30 per cent. of the ingot in order to obtain the very best results. Cases are on record where the steel bath contained only 0.09 per cent. phosphorus and 0.08 per cent. sulphur, while the segregation had 0.28 per cent. phosphorus and 0.27 per cent. sulphur. This is a comparatively new field for investigation, but its importance cannot be over-estimated. In preparing specifications, great care should be taken to specify the minimum size of ingot and the amount to be discarded.

PHYSICAL DEFECTS.

As steel solidifies, the gases it contains are forced out and take the path of least resistance. As the bubbles of gas approach the surface, they come into contact with solidified metal and are imprisoned there, forming blow-holes. These are naturally located chiefly near the surface of the ingot and are more numerous toward the top. When they are separated from the surface by only a thin skin, which may be oxidized through in heating, they do not weld up, but form various surface defects in rolling. Uneven heating and cooling sometimes results in cracks, which become seams when rolled. Steel, in cooling, first contracts until it reaches the melting point, when, like water, it expands, and, after becoming solid, again contracts. This action produces a cavity in steel ingots near the top and in the center. This is the "pipe," and, when it does not weld up, it is of course apparent in the finished work. This part of the ingot should be cut off before farther working. In steel castings this pipe is avoided by adding, above the casting proper, an additional mass of steel called the sinkhead. This is connected with the casting and is so proportioned that the pipe may come in it.

To avoid these physical irregularities in ingots, fluid compression is used in some mills. The Whitworth system is used at Bethlehem. The metal is poured into a flask of steel, around the edges of which are passages to allow the escape of the gases. This flask, after being filled, is placed under the ram of a hydraulic press, and pressure applied as high as 7000 tons on the top surface of the ingot. Under this pressure, the gases are driven to the sides and escape through the passages left for that purpose. The metal is forced down into what would be the pipe, and a perfectly solid ingot results. The segregated top is cut off, and, if a hollow forging is to be made, the inferior central metal is bored out, the result being an ingot as nearly perfect as possible.

THE EFFECT OF WORK.

Steel is hot-worked by rolling or by forging. Forging may now be again divided into hammer forging and press forging. All forms of hot working have certain effects in common. Work forces out the slag; compresses, closes up, and in some cases welds up the blow-holes and pipe, and refines the grain. These actions result in the improvement of all the physical qualities, tensile strength, elastic limit, extension and contraction. The *amount* of work alone influences the first two points, *i.e.*, reducing the slag and blow-holes, the temperature not being vital. But the refining of the grain is influenced, not only by the amount of work, but also

by the finishing temperature. It is almost axiomatic that steel finished at a high temperature will lose much of the refining effects of the work as it slowly cools and will be coarse grained in proportion to that temperature. The effect of work on the grain of steel is similar to that of heat treatment, it is also a function of the amount of kneading received. As a result of this it follows that in making large forgings it is important to use an ingot of such size that the reduction may be at least one-half. The effect of work is also inversely as the thickness of the metal, and the depth to which the good effect goes is proportional to the weight of the hammer or to the hydraulic pressure. Hollow forging under the hydraulic press gives better results, as it divides the thickness of metal by two, the mandril becoming an anvil and the reaction of the anvil itself being equal to the pressure of the ram. This is not true in hammer forging, especially if a light hammer be used, as the effect is produced only on the surface and there is a tendency to draw out the surface away from the central core. This action, together with too rapid reduction, sometimes produces actual internal rupture in the steel, which will not again weld up. Injudicious forging sometimes results, also, in a laminated structure, showing as parallel lines in a broken tensile specimen, and much reducing all the physical qualities of the metal. The hardening effect of work is also a function of the amount of carbon present. Its good effect may be entirely removed by heating to a sufficiently high temperature and slowly cooling. To illustrate this point the writer conducted a series of experiments on Open Hearth steel, varying from 0.08 per cent. to 1.20 per cent. carbon and through temperatures varying from 1000° to 1400° Fahr. These results would also be a guide to the proper finishing temperature. The following are some of the results:

Carbon.	Treatment.	Tensile Strength.	Elastic Limit.	Extension.	Contraction.	
.08 C	Unannealed	54,000	36,000	32%	65%	Carbon very low. No great effect on physical qualities.
	1400° F. Annealed	51,000	31,000	35%	70%	
1.20% C	Unannealed	145,000	84,000	3%	5%	Carbon very high. Note the great effect of temperature on all qualities.
	1000° F. Annealed	128,000	80,000	2.5%	5%	
	1400° F. Annealed	96000	46,000	19%	31%	

From such a table, backed by a sufficient number of experi-

ments, it would seem feasible to tell exactly at what temperature a steel of any carbon percentage should be finished in order that it should give the desired results.

Cold working in tension increases the elastic limit of tension and reduces the elastic limit of compression. Cold working in compression has the reverse effect. In either case it tends to reduce the extension and to make the steel brittle. These effects may be annulled by subsequent annealing. In the case of punching and shearing, the injured metal is usually removed by reaming and planing. In drawing wire and tubing, also in cold rolling and hammering, it is often desirable to retain this hardening, and consequent stiffening, effect.

HEAT TREATMENT.

The simplest heat treatment, and one to which all large forgings and castings should be submitted, is annealing. The primary object of this is to remove the bad effect of internal strains. In steel castings, which shrink twice as much as iron castings, it is absolutely necessary; for sometimes, when the pattern is complicated, the strains set up by cooling are great enough to rupture the metal. The necessity for annealing forgings increases with the carbon as illustrated in experiments noted above. Annealing removes some of the good effects of forging, while relieving the internal strains. There is therefore, in each case, a certain point which gives the best net results. Annealing always increases the percentage of extension and contraction, and generally lessens the tensile strength; but the elastic limit may be increased by annealing when the temperature is such that the good results of relieving the internal strains exceeds the reducing effect on the elastic limit due to softening. Below is one case from private notes. This example is notable also on account of the unusually high manganese and silicon present.

Manganese, 1.8% ; Carbon, 0.39% ; Silicon, 0.62%.

	Tensile strength.	Elastic limit.	Extension.	Contraction.
Unannealed	140,000	82,000	14%	23%
Annealed	118,200	88,900	22.50%	52%

HARDENING.

It has been proven that all steel is capable of being hardened. In steels low in carbon it is a question only of sufficiently high

temperature and a quenching medium of sufficiently low temperature and high specific heat. The mildest hardening effect can be obtained by plunging into melted lead. Gun, engine, and other large forgings, where no great hardness is desired and where too rapid cooling would be dangerous, are hardened in an oil bath. Cutting tools are hardened in water. Armor plate, the surface of which is very high in carbon, due to Harveying, and where the hardest possible surface is wanted, is quenched by a spray of iced water. Steel with the least possible carbon can be hardened by heating to a very high heat and quenching in mercury.

In the case of large steel forgings, for ordinary purposes, oil hardening seems to be the only practical method. Here the hollow forging again has the advantage, as it enables the cooling to take effect on both sides, giving deeper penetration and lessening the danger from internal strains. The effect of hardening is similar to that of forging, inasmuch as it breaks up the coarse crystalline structure and may even remove bad laminations. At the same time it hardens the steel and raises the tensile strength and the elastic limit, but reduces the extension and contraction so much as to necessitate a partial re-annealing. The following is an example of the effect of oil hardening on a forged bar of steel:

Carbon, 0.37% ; Manganese, 0.80%.			
	Tensile Strength.	Extension.	Contraction.
Before Hardening...............	90,900	20.0%	52%
After Hardening.................	132,400	4.5%	38%

Nickel greatly increases the hardening effect, as shown in the following case, where the carbon is ten points lower than in the above, but where the steel shows a phenomenal tensile strength after hardening:

Carbon, 0.27% ; Manganese, 0.70% ; Nickel, 3%.			
	Tensile Strength.	Extension.	Contraction.
Before Hardening.........	98,000	18%	55%
After Hardening.................	227,000	1%	not perceptible.

These were plain bars of $\frac{7}{8}$ inch diameter and hardened by the blacksmith.

As noted above, after the steel is hardened it is necessary to anneal or draw down the temper to the desired point. This point of course varies with the qualities wanted and with the percentages of the carbon and of nickel present. The following is an example:

0.66% Carbon

	Tensile strength.	Elastic limit.	Extension.	Contraction.
Annealed	127,700	66,000	12%	20.5%
Hardened and Annealed	153,300	92,000	13%	30%

This shows improvement in every quality by the double treatment.

0.46% Carbon Steel.

	Tensile strength.	Elastic limit.	Extension.	Contraction.
Annealed	98,000	48,000	21.6%	29.9%
Hardened and Annealed	104,000	61,000	22.5%	50.0%

0.14% Carbon Steel.

	Tensile strength.	Elastic limit.	Extension.	Contraction.
Annealed	72,000	41,000	31%	60%
Hardened and Annealed	74,000	44,000	31%	70%

This shows how the effect varies with the carbon. A steel may be still farther improved by being re-treated. Each hardening refines the grain, and after annealing the net effect is always a considerable gain.

Excellent qualities can be obtained in properly handled steel, but there are many reasons why steel should show bad qualities when not properly treated. It is the most valuable of materials for forgings, but the necessity of rigid specifications and of intrusting the work to those who are experienced and who have proper facilities for manufacture, must not be neglected. Most, and perhaps all, of the mysterious failures, the so-called treachery of steel, is traceable to bad composition, careless or ignorant cooling of the ingot, insufficient discard, too rapid reheating, forging under too light a hammer or too rapid reduction, insufficient work, a finishing temperature either too high or too low, and incorrect heat treatment after forging. None of these things are vital in handling wrought iron. Hence any manufacturer, accustomed to working iron only, is likely to make a poor job in the case of steel.

SURVEYING MINING CLAIMS.

By Charles Tappan, Associate Member Montana Society of Engineers.

[Read before the Society, May 8, 1897.*]

Surveys of mining claims by United States Deputy Mineral Surveyors, for the purpose of securing a patent from the United States, "must close within five-tenths of a foot in one thousand feet." (See Manual for 1895, page 10.) This requires an accuracy in the azimuth of the courses within two minutes of the true meridian. To get results within this small limit of error and to run from five thousand to eight thousand feet of lines per day over a rough mountain country is what a deputy is usually expected to do. The work is naturally divided into two heads, the Transit work and the Chaining.

THE TRANSIT WORK.

To "deflect a course from the true meridian" with an error of only two minutes, it is necessary to have a good instrument. Personal habits and tastes will cause one man to prefer an instrument that another might consider very undesirable. My own preference is for a very small and light transit, the instrument and tripod together weighing about twelve pounds and not encumbered with any solar apparatus, except a prismatic eye-piece to take direct observations on the sun. Not being familiar with the solar compass, I shall not attempt to discuss its merits, but will merely say that I have heard it reported by members of this Society as being capable of setting off a line with only one minute of error. Excellent results can be obtained by direct observations on the sun and reducing the observations by the formula

$$cos.\ \tfrac{1}{2}\ Az = \sqrt{\frac{cos.\ S,\ cos.\ (s - p)}{cos.\ \Phi\ cos.\ h}}$$

where Φ = latitude, h = sun's altitude, p = sun's polar distance, and s = half sum of the three. There are several other solutions of the triangle, but the foregoing is the shortest. When s is greater than 84 degrees this formula should not be used, because the cosine of large angles varies so rapidly. It is better, in such cases, to use the formula:

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$$sin.\ \tfrac{1}{2}\ Az = \sqrt{\frac{sin.\ (s - \Phi)\ sin.\ (s - h)}{cos.\ \Phi\ cos.\ h}}$$

Instead of depending on one sight at the sun and one reading of the circles, it is better to take either two or three sights at the sun with the telescope erect and then two or three with the telescope reversed (to do this it is necessary to have a full vertical circle); read the horizontal and vertical circles at each sighting and take the mean for the computation. This corrects errors arising from non-adjustment of instrument, especially errors in the collimation, from unequal height of standards and in the vertical circle. It takes only a few minutes longer to take the several sights and readings.

Always take a sight at the mark or foresight after observing the sun, to be certain that the transit has not moved during the observations. If the tripod has been wet, and if the observation is made the first thing in the morning, the heat of the sun may easily turn the transit two or three minutes. If possible, observations should be taken both before and after noon. The latitude usually offers the greatest difficulty in this method of getting the course. It is so often inconvenient to take a latitude observation at noon, that the great majority of these computations are made from latitudes calculated from the public surveys. As the error in latitude, for a morning observation, causes an error in the result with an opposite sign from that of an afternoon observation, the mean of the two, provided they are taken at equal hours from noon, should give the correct azimuth. By using Professor Johnson's "Table of Errors in Azimuth by Solar Compass" (reprinted in Gurley's "Ephemeris"), one can compare morning and evening observations taken at different hours from noon. For example, observations at latitude 40 degrees at 10 A.M. and 5 P.M. give a difference of four minutes in azimuth. By the table, the morning observation would be 2.6 minutes, the evening observation 1.3 minute out, and the latitude one minute out. By making a new set of computations with corrected latitude, one can ascertain whether the difference is actually occasioned by using the wrong latitude, or by some other error. If the former, the observations may be considered correct. If the latter, a new observation should be made.

In running lines, it is not usually necessary to use hubs with tacks. Almost always, in a mountainous country, unless the timber is heavy, a backsight or a foresight upon a distant object makes it easy to keep a line straight within an inch in fifteen hundred feet, without being over careful in centering at each hub. It

is very convenient, for future use, to sketch, in the field-book, the object used as a sight, and show the cross wires in the sketch.

CHAINING.

The long, thin steel tape is now almost universally used in this kind of surveying. The length of tapes depends greatly upon the character of the country, whether rolling hills, rough, rocky mountains, timbered or open. In the Upper Yellowstone country I first used a 300-foot tape, but the country was either so exceeding rough, or else so heavily timbered, that about as rapid progress could be made with a 200-foot tape. In Utah, especially in the foothills, distances of five hundred feet and more can very frequently be covered with one stretch of the tape. Experiments on a carefully measured base 492.4 feet long, across a gulch, showed that a 500-foot tape could be stretched by two men of ordinary strength, using a pull of probably seventy pounds, to within less than one-tenth of a foot of the actual distance. The pull was not measured by a spring-balance. It was as heavy a pull as could be conveniently made by a one hundred and fifty pound man, with the tape held as high as the telescope of the transit. In these experiments the tape was suspended clear of all supports, the angle of elevation, from one station to the other, was 5 degrees, the length of tape between stations 494.3 feet, which, multiplied by cosine 5 degrees, is = 494.42 feet. The tape was an ordinary Roe & Sons tape, marked every five feet with brass or copper plates, and every foot with a rivet. It is best to measure from the end of the telescope axis, and to measure the vertical angle to the hand of the head chainman. The precision with which the vertical angle should be measured depends upon the steepness of the slope. For slopes less than 20 degrees, it is sufficient to read to fifteen minutes. For reducing the measured distance to the horizontal, the most convenient thing to use is an old-fashioned traverse table, such as is found in Scribner's "Pocket Book," or Roe's "Pocket Book." These have distances to one hundred for each $\frac{1}{4}$ degree. As the tables are to two places of decimals, they can be used for distances up to one thousand feet for one decimal.

The error that most frequently enters into this method of chaining is that of reading the tape length ten feet wrong; *e.g.*, one has the 178-feet rivet, the first thing noticed is that the unit is 8, and as the 180-feet plate is the one seen first, the distance may very easily be written 188 in the note-book. By having the back flagman hold the back end of the tape upon the last station, one can double chain every line at the expense of very little extra time, except

where the country is so open that the head chainman can proceed before the deputy reaches the next station. It is a very good practice to check by stadia. As stadia rods are always cumbersome, it is desirable to find some good substitute. A piece of stout canvas about one inch wide, six feet long, and painted like a Philadelphia leveling rod, with a plumb and bob fastened to one end, can be easily read up to distances of five hundred feet, and when held by the top is sure to be plumb. This pocket rod is also very convenient in setting hubs that are hidden by intervening rocks or low brush, and for measuring distances to corners of buildings and other improvements, where extreme accuracy is not essential.

A very pretty check on the chaining of long lines can be made whenever some distinct object is visible from both ends of the line and from one or more points along the line. Say the line is fifteen hundred feet long, and at the start a dead tree-top is seen 30 degrees to the left. By measuring the angle to the tree-top at five hundred, one thousand and fifteen hundred feet, one has the base and two angles of three adjacent triangles. If the line common to two triangles is the same length when computed from either triangle, it follows that the line measured is correct. It takes but a few seconds to measure the angles, and a few minutes to make the computations. If the object is properly situated, it can be used as a check on the end lines.

DISCUSSION.

Mr. John Herron.—Mr. Tappan's paper is an expression of that improvement which the practice of to-day shows over the work of past years. It surely speaks well for the profession when we see these attempts to make surveying something more than a mere trade. It has long been customary to consider accuracy non-essential in the survey of the surface lines of a mining claim, and there are but few of us who have criticised the work of our fellows as lacking in this respect. The calculation of field notes may show that a survey has closed within the prescribed limits of errors, and yet the actual positions of corners and lengths of boundary lines may vary greatly from the result of the calculations.

There is no gainsaying that the official survey of a mining claim should be exact—not an approximation. It is useless to lay down rules which give results that are "close enough." Those of us whose work has led into the projection of the boundary lines of claims to the lower levels of deep mines, know what a few feet may mean in the proximity of an ore body.

No surveyor nowadays trusts his chainman to hold a tape line horizontal on a steep mountain side. It cannot be done except in such short lengths that the frequent "breakings of chain" is in itself a source of error. The method of chain measurements outlined by Mr. Tappan is the one productive of best results, where reasonable speed is desired. If carefully done, it will vary but little, in the length of an ordinary claim, from the result obtained by measuring the slope distance between points as an hypotenuse, obtaining the perpendicular by a line of levels, and calculating the base for the horizontal distance. This is tedious, if the line be long, as the result required is the sum of the bases of a number of triangles—depending on the length of the chain or tape used. I differ from Mr. Tappan as to the utility of transit points. For good work I believe in placing hubs with tacks at every chain-length, using every other one as a transit point. Then, with an assumed datum as the elevation of the starting point, noting the height of instrument, the vertical angle is read to the first station ahead and the slope distance from axis of instrument is measured. Then, moving to the second station, the vertical angle and the slope distance are taken, back to the first station, and ahead to the third station, after which the transit moves to station No. 4. The advantage of this method is that, simultaneously with the transit line, a line of levels is being carried on which may be of great use—some day—to some one, if not to the man who makes the survey. It also offers a method of checking work, as satisfactory as the stadia, for a vertical angle can be read to any point on the line whose elevation has already been determined, which elevation should be the present height of instrument, plus or minus tangent of vertical angle multiplied by horizontal distance, as shown by notes.

The writer has in mind an example of extreme accuracy in a survey made in this manner. In the trial of an important mining suit the respective parties exhibited maps of the claims in controversy, including the underground workings. One map had been prepared from very careful triangulation surveys, extending over a period of several years, and from carefully run lines of levels. The other map was prepared from notes of surveys made in the manner referred to. Both maps showed surface and underground workings extending over a distance of about half a mile in plan, and comprising several miles of actual surveys, yet tracings of both maps corresponds almost exactly, and levels between points nearly six hundred feet apart vertically, which required three-quarters of a mile of surface and three-quarters of a mile of underground surveys, checked within 0.52 feet.

Meteorological Investigations in the Free Air, at the Blue Hill Observatory, Milton, Massachusetts.

By A. Lawrence Rotch, S.B., A.M., Director.

[Read before the Boston Society of Civil Engineers, May 19, 1897.*]

In their relation to the atmosphere, men resemble organisms which inhabit the depths of the ocean; and the slowness of the development of meteorology into a science is due to the difficulties of exploring the aërial ocean. The earliest attempts to explore the upper air were, of course, made by mountain and balloon ascensions, and it is worthy of remark that the first scientific balloon voyage was made by a Bostonian, Dr. John Jeffries, in 1784, from London. During the next century there were many high balloon ascents. In 1862, Glaisher, in England, rose nearly six miles, and, in 1893, Berson, in Germany, reached about the same height, and, with improved instruments, obtained, for the first time, trustworthy data. Balloon ascents, however, are sporadic and give little information about the atmospheric changes which occur from day to day. Continuous observations can be made only on mountains, and in this respect great strides upward have been taken during the past twenty years. The French have expended the most money on their outposts, which are fortresses to withstand the fury of the elements, but the most valuable results have been derived from the Austrian stations under the direction of Dr. Hann. The highest meteorological station in the world, which, instead of observers, has an automatic recording apparatus made by Mr. Fergusson at Blue Hill, is maintained by the Harvard Observatory on El Misti, in Peru, at an elevation of over 19,000 feet.

The Blue Hill Observatory is not a mountain station, but the conditions there are approximately those of the free air just above the surface of the earth. As an illustration of the effect of the friction of the ground on the wind, it may be stated that its velocity on Blue Hill averages 60 per cent. greater than on the tower of the Post Office in Boston, only 460 feet lower. The influence of the artificial heating of a city, in raising the air temperature, is shown by the fact that the difference between the Boston and Blue Hill temperatures in winter is greater than the mean difference for the year, which is about three degrees.

I now come to the special subject of my paper, the investigation of the free air from the summit of Blue Hill. Soon after the

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foundation of my Observatory, in 1885, detailed cloud observations were begun by Mr. Clayton, and nowhere else in the United States has so much attention been given to the study of clouds. There is a long record of the amount of cloud at each hour, consisting of personal estimates during the day and of an automatic record at night by an instrument called the Pole Star Recorder, which gives a continuous photograph of the sky around Polaris. When the trail of the star on the photographic plate is unbroken the sky around Polaris is clear, while when the trail is broken or

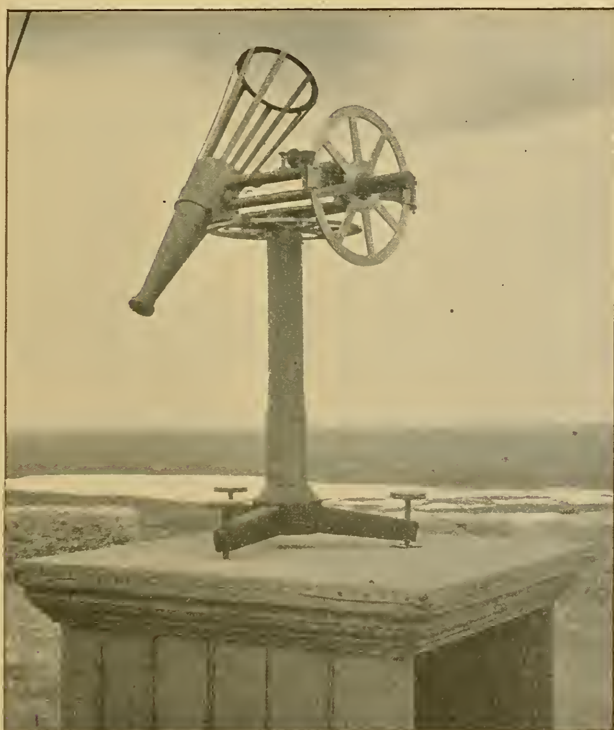

FIG. 1.

obscured the sky is partly or entirely covered with clouds. The direction of motion and relative velocity of the clouds are frequently observed by means of a cloud mirror or nephoscope. The measurement of cloud heights was begun in 1890 by Messrs. Clayton and Fergusson according to the system previously used at Upsala in Sweden. These theodolite measurements were again undertaken last year here, and also in Washington in connection with an international scheme of observation. The method is as follows:

At two stations, a mile or more apart, two observers each with the specially constructed theodolite shown in Fig. 1, measure the azimuth and altitude of some point of a cloud whose identity is assured by telephonic conversation. Synchronous observations are secured by the beating of an electric pendulum. The probable error of the calculated heights of the highest clouds is only a few hundred feet. Simultaneous observations of the position of the cloud, at a definite interval of time, enable its velocity to be calculated, or this may be obtained from the relative velocity when the height is known. Four other methods of measuring cloud heights are employed at Blue Hill. One of them is by the shadows of low clouds. The angle of the cloud from the Observatory is measured, the angle of the sun with the horizon is found from tables, and the distance of the shadow on the landscape is ascertained from a map. These elements of a triangle enable the cloud height to be calculated, and its velocity may be determined from the time of passage of its shadows over known points. The only method of measuring certain high and uniform cloud strata is by means of the light reflected upon them at night from cities. The angle which the center of the illumination makes with the horizon is measured; and, having the distance of the city, the right-angled triangle may be solved. An accurate method for low and uniform clouds is to send up kites into and through the clouds. The amount of line and its angle when the kites disappear give the height of the lower surface, and the records of barograph and hygrograph, which are carried by the kites, determine the upper limit of the cloud, and, therefore, its thickness. Still another method, for very low stratus or nimbus, is to note the height of the base on the sides of Blue Hill.

As a result of these measures, the heights and velocities of drift of the various clouds are accurately determined. The mean height of the cirrus cloud is about 29,000 feet, though it is sometimes found as high as 49,000 feet. The mean height of the cumulus is 4600 feet, or a little less than a mile, but the tops of the cumulo-nimbus, or thunder-shower clouds, penetrate into the cirrus region. The average height of the nimbus, or rain-cloud, is only 2300 feet, and it often sinks below the top of Blue Hill. The average velocity of the cirrus clouds is 89 miles an hour, but in winter they sometimes have the enormous velocity of 230 miles an hour. The observations show that the entire atmosphere, from the lowest to the highest level, moves twice as fast in winter as in summer, and that between heights of two and nine miles there is an almost continuous westerly current of great velocity, the in-

crease of velocity from the lowest to the highest clouds being a linear function of the height. Whenever clouds are visible, therefore, it is possible to ascertain the direction and velocity of the currents at the levels at which they float. Those readers who are interested in the subject of clouds will find a discussion of the Blue Hill and related data, by Mr. Clayton, in Part v, of vol. xxx, of the *Annals of Harvard College Observatory*, which a competent writer in *The Nation* has termed "by far the most thorough study of the kind ever undertaken in this country, if not in the world."

More important factors in the science of the weather, because they are causes rather than effects, are the changes of barometric pressure, air temperature and humidity with height. The former can be determined only by observations at fixed heights, as on mountains, but the other elements are greatly affected by the mass and covering of the mountain upon which the observations are made. I have already stated that daily observations in free balloons are impossible, while their rapid passage through the air makes observation at fixed points difficult. Moreover, the balloon itself, heated by the sun, affects the temperature readings unless special means are taken to avoid this, and so all the early balloon observations are probably more or less inaccurate. Captive balloons have been tried for exploring the lower air, both with observers and with self-recording instruments without observers. Their height is necessarily limited by the weight of cable, and strong winds drive them down, so that heights exceeding 2000 feet can hardly be attained. Their cost, also, is a drawback. Kites have none of their disadvantages and they fail only when there is too little wind at the ground, a condition which seldom extends aloft.

The honor of making the first thorough exploration of the lower mile of free air belongs to the Blue Hill Observatory, and especially to Messrs. Clayton, Fergusson and Sweetland, my assistants, who have devised new apparatus and methods, and have carried the work to such success that it is being imitated in this country and in Europe.

Although the first scientific use of kites is commonly attributed to Franklin, it is now known that three years previously, that is, in 1749, Dr. Wilson, in Scotland, sent into the clouds thermometers attached to kites, and in 1822 the temperature in the Arctic regions was obtained by self-registering thermometers raised in this way. The first systematic use of kites in meteorology was in 1883, when Archibald, in England, obtained differential measures of wind velocity by anemometers attached to kites flown tandem with steel wire. These instruments indicated only

extremes or totals, and it was necessary to record graphically and continuously before simultaneous observations could be obtained at the ground and in the free air, and upon doing this depends the value of our work at Blue Hill. Up to this time self-recording instruments were too heavy to be lifted by kites, but Mr. Fergusson remodeled a Richard thermograph so that it weighed only 24 ounces and, on August 4, 1894, this instrument was elevated about 1500 feet above Blue Hill. Since then, meteorographs recording three elements and weighing less than three pounds have been constructed by Mr. Fergusson, and by M. Richard for use at Blue Hill. They record atmospheric pressure, air temperature, and either relative humidity or wind velocity.

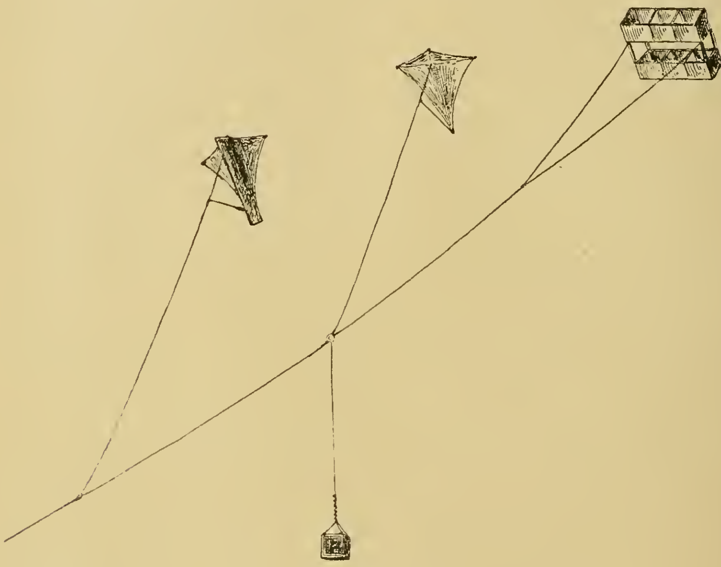

FIG. 2

A factor in the success attained was the substitution of steel music-wire for cord as a kite-line. The wire has the same weight as the cord, and is twice as strong and only one-sixth the diameter. This reduction of surface exposed, is important in lessening the wind pressure. The wire now used is No. 14, M. W. G., having a diameter of 0.033 inch and a tensile strength of about 300 pounds. Thus the analogy of these aërial soundings to the deep-sea soundings is borne out, and it will be completed by the substitution of a strain pulley and a storage reel, similar to that used in deep-sea sounding, for the present drum, which threatens to collapse under the accumulated pressure of the coils of wire. Several forms of kites are employed, such as the Eddy or Malay tailless kite, the

Hargrave or cellular kite, and, latterly, a kite with a keel on the front surface, devised by Mr. Clayton. These are shown lifting the metrograph in Fig. 2, while Fig. 3 gives a general view of the Observatory with the kites and the hand-reel. The kites weigh from two to three ounces per square foot of lifting surface which, in a twenty-five-mile wind, exerts a pull of about one pound on the line. The meteorograph is hung between two kites and other kites are attached to the wire at intervals so that its angle above the horizon shall not fall below 30° or 40°, notwithstanding the increasing weight of wire (15 lbs. per mile) and the pressure of the wind upon it. The pull on the windlass is recorded by a dynamo-

FIG. 3.

graph. A measuring device registers the length of wire uncoiled, and from this and from the angular elevation of the meteorograph, its vertical height is computed, after making allowance for the sag of the wire, which amounts to about two per cent. of its length. When the meteorograph is hidden by clouds, differential measures of its heights are obtained from its barometric record.

To sum up briefly the results, I may say that about 130 records have been obtained at all seasons and in all kinds of weather, with winds varying from fourteen to forty miles per hour. Several records have been brought down from more than a mile above the hill, and last October the maximum altitude of 8740 feet above the

hill, or 9370 feet above the sea, was reached. From the direction of the kites in different air strata, the change of direction of the wind at various levels is determined. Usually there is an increase of wind with altitude, the rate of increase being about 25 per cent. in the first 1000 feet. The changes of temperature and of relative humidity are often very abrupt. Thus, before a cold wave is felt at the earth's surface, the normal decrease of temperature with elevation (about 1° per 250 feet) is much accelerated, and before a warm wave comes on below, a marked inversion of temperature at a height of half a mile has several times been noted. The observations, so far as studied, seem to show that, at a height of a mile,

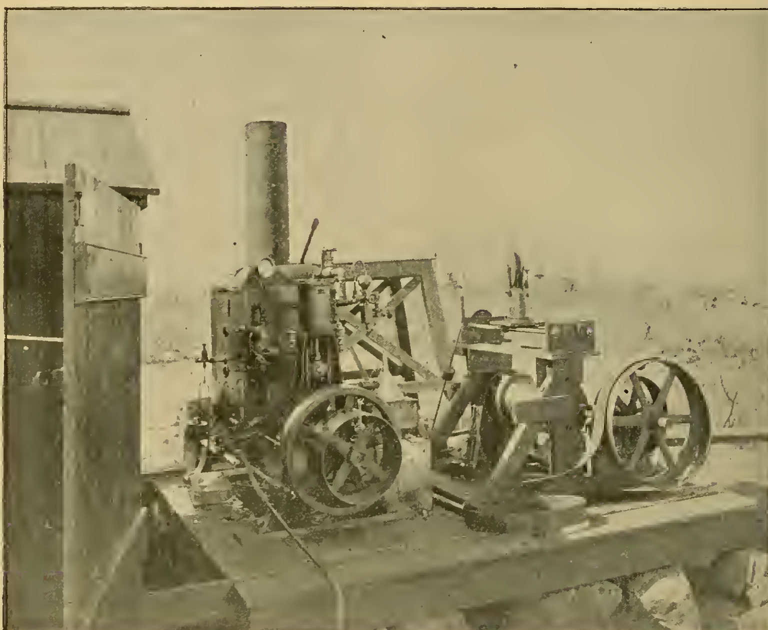

FIG. 4.

there is no diurnal change of temperature, but that in fair weather the days are damp and the nights are dry, or the reverse of what occurs at the earth's surface. A discussion of the observations will be published in the Annals with the Blue Hill observations for 1896. By means of a grant from the Hodgkins Fund of the Smithsonian Institution, a steam reeling apparatus was constructed last winter, and Fig. 4 shows the first application of steam to kite-flying. With perfected apparatus during the coming summer, it is confidently expected that records will be obtained at an altitude exceeding 10,000 feet above Blue Hill.

Editors reprinting articles from this journal are requested to credit both the JOURNAL and the Society before which such articles were read.

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OPERATION OF THE LOS ANGELES OUTFALL SEWER AND SEWAGE IRRIGATION.

BY BURR BASSELL, MEMBER TECHNICAL SOCIETY OF THE PACIFIC COAST.

[Read before the Society, May 7, 1897.*]

A DESCRIPTION of the sewerage system of the city of Los Angeles was published in *Engineering News* of February 28, 1895. This included an account of the construction of the Outfall Sewer, which had been completed in the spring of the previous year. After a lapse of two years, the writer of the article feels warranted in giving an account of its operation.

The experience derived from the working of this plan, for sufficient time to test its merits will furnish valuable lessons for engineers and irrigators.

An apology is due the Society for presenting the subject matter of this paper in its present form; but owing to circumstances over which the writer had no control, he is compelled to do so, or else fail to present the paper as announced. His aim, therefore, has been to induce discussion and make the paper suggestive rather than exhaustive.

Map and profile of the Outfall Sewer, together with details of the most important structures, are shown on plates 1, 2 and 3.

The accompanying photographs may also serve to make the subject matter a little clearer.

Fig. 1. View of wood-stave pipe construction on Section 3.
Fig. 2. Blow-off on first siphon.
Fig. 3. Irrigating hydrant.

*Manuscript received July 10, 1897.—Secretary, Ass'n of Eng. Socs.

Section.	Name of Contractor.	Contract Price.	Construction. Begun.	Construction. Finished.	Length Feet.	Size and Character of Section.	Barrels of Cement Used	Remarks.
1	J. Rebman.	$12,018	Jan. 25, '93.	April 1, '93.	2,463	52 in. circular, two rings brick.	1,174	This section built large enough to carry the sewage of a city of 135,000 population.
2	Frick Bros.	24,085	Jan 5, '93	March 17, '93.	4,435	40 in. circular, two rings brick.	1,734	Only one line built at present
3	Mansfield & Grant.	39,000	Sept. 6, '93	Feb. 8, '94.	16,936	38 in. wooden stave pipe.	49	Secs. 3 and 6A required about 700,000 ft. B. M. Cal. redwood.
4A	Mackay & Young.	31,033	May 25, '93	Dec. 6, '93.	4,677	40 in. brick conduit, and 6 ft. oval tunnel.		1,883 lin. ft. brick conduit; 2,794 lin. ft. brick and concrete tunnel.
5A	Mackay & Young.	30,091	Aug. 11, '93	Nov. 10, '93.	3,842	6 ft. oval tunnel, 40 in. circular brick.	5,012	2,995 lin. ft. brick and concrete tunnel; 847 lin. ft. brick conduit.
6A	Mansfield & Grant.	38,450	Aug. 10, '93.	Jan. 10, '94.	17,174	36 in. wooden stave pipe.	72	All concrete specified, 1 cement, 2 sand, 6 gravel.
7	Frick Bros.	27,454	April 10, '93.	June 15, '93.	6,052	40 in. circular brick conduit.	2,292	All mortar for brickwork, 1 cement, 2 sand.
8	Hughes & Mayer.	24,602	June 15, '93.	Sept. 16, '93.	4,778	40 in. circular brick conduit.	1,583	
9	Frick Bros.	29,223	June 10, '93.	Oct. 11, '93	4,060	40 in. circular brick, and 6 ft. oval brick and concrete tunnel.	1,490	1,976 lin. ft. of brick conduit; 2,084 lin. ft. of brick and concrete tunnel.
10	Hughes & Mayer.	10,735	Sept. 25, '93.	Nov. 30, '93.	1,200	24 in. cast iron pipe.	3	Flanged pipe with pure rubber band between each joint.
Totals		$266,691			65,628 = 12.4 miles.		13,400	

Figs. 4, 5 and 6. Views of launching cast-iron pipe.

Figs. 7 and 8. Break in Lateral No. 1.

For convenient reference the writer submits a table, as published in *Engineering News*, giving, for each section, the name of the contractor, date of construction, size and length of section, character of materials, quantities, cost, etc.

Those who may not have access to the files of that journal may be interested in a brief description of the Outfall Sewer, and some account of its construction.

The Outfall properly begins within the city limits at the intersection of Grand Avenue with Jefferson Street, and extends in a southwesterly direction to the Pacific Ocean, a total distance of 12.4 miles.

The line was divided into ten working sections of unequal lengths, and separate bids were received for each section, complete.

Section 1 is a circular brick conduit, 52 inches in diameter, 2463 feet in length, having a grade of 1 in 600. From the end of Section 1, the Outfall will eventually be a double conduit, excepting the tunnel portions, which were made large enough to carry the sewage of both conduits when built. Provision was made also at all structures for the second conduit.

Section 2 is a circular brick conduit 40 inches in diameter, 4435 feet in length, having a grade of 1 in 800. This gradient is maintained by means of vertical drops for all the remaining portion, excepting the siphons and the ocean section.

A settling chamber, designed to collect sand and other heavy substances, was built at the end of Section 2. It has four compartments, consisting of a receiving and discharge chamber at the ends, with two elongated apartments between, separated from the end chambers by a double set of boiler-plate sluice gates. The middle apartments are provided with sand-pits 4 feet deep, with horizontal screens over them, on the grade line of the sewer.

Section 3 embraces the first wood-stave siphon, which is 38 inches in diameter and 16,936 feet in length. On this section there are three blow-offs and five hydrants, with several additional manholes. The lowest portion of this siphon is about 27 feet below the hydraulic grade line. At the lower end was placed a butterfly valve provided with a geared handwheel, for easy manipulation.

Sections 4 and 5 are each partly in tunnel and partly in 40-inch brick conduit. The lengths of the tunnel and of the brick conduit are 5789 feet and 2730 feet respectively, aggregating 8519 feet for the two sections.

The tunnels are lined throughout, having a semi-circular

invert of concrete, and an egg-shaped arch of brick-work. In section they are 4½ feet wide and 6 feet high. The average cross-sectional area of the excavation was about 52 square feet. The material encountered was mainly sand, and in places very fine and difficult to handle.

At the end of Section 5 is a drop-chamber, provided with gates for delivering sewage to Lateral No. 1.

Section 6 embraces the second wood-stave siphon, which is 36 inches in diameter and 17,174 feet in length. On this section there are seven hydrants, beside several manholes. The structures provided for delivering sewage to Laterals No. 2 and 3 will serve the purpose of blow-offs when necessary.

The lowest portion of this siphon is about 25 feet below the hydraulic grade line. It may be well to state, in this connection, that one straightway valve has been placed in each siphon since the sewer was finished, as will be noted later on.

The end of this siphon is provided with a butterfly valve, similar to the one at the end of the first siphon.

Sections 7 and 8 are 40-inch brick conduits, and aggregate 10,830 feet in length.

Section 9 has 1976 feet of brick conduit and 2084 feet of tunnel passing through the sand dunes skirting the coast.

The Ocean Section (No. 10) consists of 1200 feet of 24-inch cast-iron flanged pipe, extending originally 600 feet into the sea.

The pipe was bolted together with a ring of pure rubber, ¾ inch square, in each joint. This gave sufficient flexibility to the line to permit launching in the following manner:

On the sloping shore-front about 600 feet of pipe was first bolted together and placed upon two timber stringers, one on each side, to which the pipe was fastened by ¾-inch rods. Wooden rollers were placed between these stringers, and two lines of boards, 2 inches by 12 inches, were laid upon the ground. This whole line was then slowly moved out to its final position by means of capstans, operated by horse power. Figs. numbered 4, 5 and 6 show quite clearly the manner of launching. No attempt was made to anchor the pipe, or to protect in any way the portion lying on the ocean bed, the outer end being submerged in about 20 feet of water.

Littoral currents, resulting from heavy storms, have shifted the pipe about fifteen (15) feet out of alignment, causing it to break on shore at a point about one hundred feet from line of low tide. As soon as this occurred, the sewage, rushing out of the pipe at great velocity, cut out a large basin which kept constantly

encroaching upon the bluff. Section after section of the pipe broke off and dropped into the pool below. To stop this action, a short line of sheet piling was driven, at right angles to the sewer, near the base of the bluff, and a wooden flume was constructed to carry the sewage out some distance beyond. This is, of course, only a temporary solution of the difficulty. The sewage eddies around in a large circular pool, and has cut a channel northerly along the base of the bluff for about four hundred feet. It there flows into the ocean.

Upon examination of the exposed portion of the pipe, lying only partially imbedded in the beach sand, the writer observed that many of the bolts of the flanged joints were missing; that the rubber between the flanges seemed to have hardened, and that the $\frac{3}{4}$-inch rods, used at the time of launching to hold the pipe to the wooden stringers under which the rollers were placed, were entirely rusted and worn apart.

It is hoped that some of the following points of constructive details and experiences may call forth discussion from members of the Society:

The most important change or addition to the settling-chamber, which has been made as a result of practical experience, consists of an emergency wasteway conduit, 24 inches by 30 inches, connecting with the first apartment of the chamber. The conduit is provided with an ordinary sluice-gate with emergency overflow opening at the top.

This branch enables the superintendent to use the sewage on about four hundred acres of land which could not otherwise be irrigated, being higher than the first hydrant.

An additional grating, made of 1-inch iron rods placed vertically in front of the 38-inch siphon, and spaced 6 inches apart, center to center, was deemed necessary by the superintendent, after finding that some malicious person had dropped an empty barrel into the chamber below the rubbish screen first constructed.

The superintendent visits the chamber daily, and with a long-handled fork, having suitably curved prongs, forks the accumulated rubbish off the screens, and deposits it in closed boxes placed flush with the surface of the ground at each end of the chamber. These are carted away weekly at a cost of 50 cents per week.

A large quantity of fine sand accumulates in the pit and at the corners of the chamber. This is cleaned out about twice a year, but much the larger portion passes on through the sewer. In the article to which frequent reference is here made, the writer expressed his opinion that this chamber would prove useless except as a rubbish collector.

Regarding its use as a sand-box and arrester of "valuable articles," as advocated by the City Engineer, he is of the same opinion still. It has been made to serve a useful purpose, however, as an emergency wasteway and point of diversion for sewage irrigation.

The horizontal screens proved a nuisance when the chamber was being cleaned, and were abandoned as useless.

The specifications called for "hard-burned brick, with a crushing strength of not less than 2500 pounds per square inch." The brick and concrete work were both exceptionally good, largely due to the fact that the city furnished all the cement used, and also to the painstaking care of Mr. H. P. Vincent, the engineer who designed and superintended the construction of the sewer, who insisted upon the specifications being fully complied with.

The bricks were of a superior quality, and were thoroughly wetted by immersion before using. This is one of those small details the observance of which will cover a multitude of sins committed by masons.

The specifications for wooden pipes called for round rods of $\frac{5}{8}$ inch diameter, medium steel, with nuts not less than $\frac{7}{8}$ inch in thickness. The threads were to be of Franklin Institute Standard as to form, but to have sixteen threads per inch.

In the article referred to, it was stated that trouble was experienced during construction by the stripping off of the nuts while cinching the pipe, and that, upon finding they were not always uniformly and properly cut; this was thought to be the cause of the trouble. Others claim that there should not have been as many as sixteen threads per inch.

The cast-iron shoe used is locally known as the "Register Patent," and is faulty in at least one feature, viz: that the bands cross each other in such a manner as to produce a shearing strain on the projecting points. The first shoe used was cast so light that a large percentage of these points would break; the shoes were then made heavier, weighing three pounds each, and better results were obtained.

Considerable trouble was experienced also in making the siphons water-tight, owing to the fact that the wood-stave pipe was laid by inexperienced workmen and not properly cinched. The importance of seating the bands well into the staves by means of wooden mallets during the process of cinching was clearly demonstrated.

At structure 43A, the siphon deflects to the right $56\frac{1}{2}$ degrees, and, on account of the narrow right-of-way secured (15 feet), a boiler-plate knee was used in preference to a curve.

During the rush of construction, the City Engineer asked the writer to design a drop-chamber for structure No. 67, at the end of Section 8. He did so, making the length twelve feet. This design was criticised by some of his superiors as being unnecessarily large. The writer maintains that the *mean* velocity of approach should not be made the governing factor in determining the path of the jet, and that the graphical method, usually employed in such cases, showing parabolic curves, is incorrect. He hardly expects this statement, however, to lead to a Fanning-Frizell discussion.

Having observed the flow at this drop when the sewer was carrying only 10 second-feet, or less than one-third its full capacity, and that the overfall strikes the toe of the opposite wall even with a vertical drop of 10.61 feet (not including the water cushion), he is confirmed in his statement and thinks the mathematicians should revise their figures.

The necessity for blow-offs in the line of the first siphon is called in question by several engineers, and their practical utility remains to be demonstrated. The form of hydrant, shown in Fig. 2, would indeed be a pronounced success if one wished to take a sewage bath. Not being in demand for this purpose, they have all been incased in a wooden box, with an outlet on one side leading to the irrigating ditch.

Figs. 7 and 8 show a break in Lateral No. 1, which was built by private parties, and which is used to convey sewage to the lands of Messrs. Howard and Bixby. No comment is necessary upon the failure of the structure, the photographs clearly showing faulty design and workmanship. The bottom, sides and top were never properly united. It has been repaired by bolting together the ends of light iron rails, bent to the form of the conduit, and spacing them about four feet apart to hold the concrete together.

In order to permit the use of sewage from the upper portion of the siphon sections, and to avoid subjecting them to the pressure resulting from closing the valves at their extreme lower ends, two straightway valves, of the Ludlow pattern, were placed immediately below structures Nos. 19½ and 44A. A further reason for these gates was found in the excessive leakage of the butterfly valves, it being impossible to shut off all the flow in this way. The first butterfly valve has been entirely removed, owing to the accidental twisting off of the valve-stem.

No sewage has ever been used for irrigation from the lower portion of either siphon. Probably the most important question of constructive detail relates to the proper form of gates for an outfall sewer similar to the one we have under consideration.

Some engineers will doubtless claim that the butterfly valves were faulty in design, others that the principle of the butterfly valve is faulty. Those who defend the butterfly construction maintain that the sewer should never be permitted to become dry, because of accumulations that adhere to the invert.

The straightway valves were put in place about April or May, 1895, and they have given entire satisfaction through two seasons. Mr. H. P. Vincent, superintendent of construction of the Outfall, claims that he only followed instructions in designing such gates as were called for by the plans approvéd by the consulting engineer, the late Mr. P. J. Flynn. Mr. Vincent has always had grave doubts, however, as to the successful working of straightway valves in a sewer. These valves are massive and heavy, provided with slow-motion gear, requiring about twenty minutes to open or close. They have been placed in brick substructures with a wooden superstructure. In connection with each valve an air vent or iron stand-pipe, six inches in diameter and forty-two feet in height, has been placed a few feet below the valve.

The necessity for these vents has been called in question by at least one well-known engineer, who claims that the only pressure to which the lower portion of the siphons would be subjected, upon closing the gates, is measured by the difference in elevation between the lower ends of the siphons and the gates. This difference in elevation does not exceed five to seven feet. The writer must confess that he failed to comprehend the argument. It was even denied that a partial vacuum was formed below the valves, or that there would be any tendency in the pipes to collapse. Surely these are elementary principles of physics and hydraulics, but since they have been called in question by those entrusted with important hydraulic work, no excuse need be made for bringing them forward for discussion.

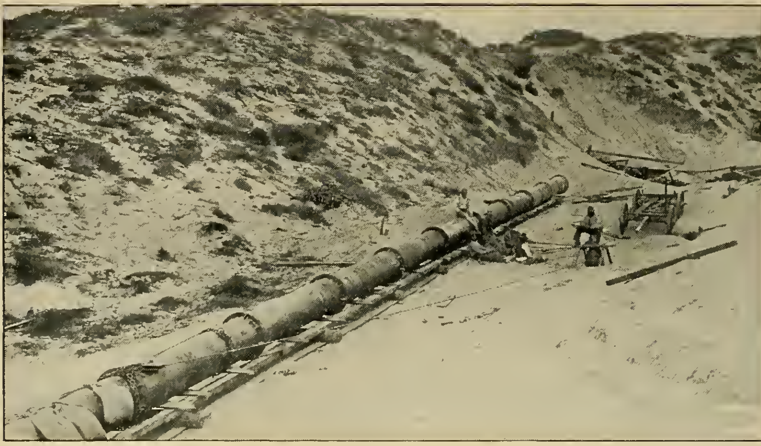
Upon witnessing their action, it seemed that some provision for an air vent was necessary. After the gates are three-quarters closed the air rushes into the siphon with great velocity, to fill the partial vacuum made by the outgoing sewage, causing the standpipes to vibrate to some extent and to sing like an Eolian harp. When the gates are finally closed, and for a short time before and after, the reaction within the pipes is so great that sewage is thrown out of the top of the stand-pipe for a distance of ten feet, or more than fifty feet above the sewer. The writer, on one occasion, saw a large ink bottle and other foreign matter thrown out in this manner.

A description of sewage irrigation along the line of the Outfall Sewer, and as conducted by the South Side Irrigation Com-

FIG. 1.
WOOD-STAVE PIPE CONSTRUCTION ON SECTION 3.

FIG. 2.
BLOW-OFF ON FIRST SIPHON.

FIG. 3.
IRRIGATING HYDRANT.



Figs. 4, 5 and 6.
Launching Cast-iron Pipe.

pany and at the sewer farm of the city of Pasadena, will probably be of interest to irrigators and to those directly entrusted with sewage disposal.

The following acreage was irrigated along the line of the Outfall Sewer during the past two seasons:

In the district west of the settling-chamber, about four hundred acres. In the vicinity of structure 19½, four hundred acres. Lands reached by Lateral No. 1, three hundred and fifty acres. In the vicinity of structure 44A, four hundred acres. Total, fifteen hundred and fifty acres.

The total amount of sewage, used upon the above acreage, varies from eight to ten second-feet, or four hundred to five hundred miners' inches.

The first eight hundred acres irrigated from the sewer, being near the city, is devoted mainly to the raising of vegetables.

The land reached by Lateral No. 1 is planted in corn and other field crops. Of the remaining acreage in the vicinity of structure 44A, about one hundred acres is planted in potatoes and cabbage and three hundred acres in corn.

The City Engineer's reports for the years 1895-96 show that the sewer had yielded a small revenue, and it is reasonable to predict that this income will increase from year to year.

The receipts from the sale of sewage for 1895 amounted to		$3278.00
Cost of maintenance:		
Salary of Superintendent	$1000.00	
Assistants and labor	625.47	
Cleaning settling chamber, repairs, etc	512.50	
		2137.97
Net revenue		$1140.03
Receipts for the year 1896		4009.50
Cost of maintenance:		
Salary of Superintendent	$1200.00	
Assistants and labor	1675.40	
Repairs, etc	184.80	
		3060.20
Net revenue		$949.30

In 1883 the city of Los Angeles boasted a population of about twenty thousand, and was at a loss to know what to do with its sewage. In a fit of desperation it entered into a contract with the South Side Irrigation Company, above named, and obligated itself to *give away* to said company "all the sewage matter of every kind flowing through the San Pedro Street Sewer," amounting to 3.585

second-feet, or 180 miners' inches, and the right to use the same for a period of eighteen years.

In October, 1895, a second contract was made with the same company, whereby the city agrees to deliver 120 inches more for a period of six and one-half years, or until the expiration of the former contract. For and in consideration of this last amount, the said company has laid a cement pipe, 24 inches in diameter, 6000 feet of which lies within the city limits, and becomes the property of the city at the expiration of the lease.

In addition to the three hundred inches above mentioned, said company has the first right to use an additional one hundred inches, paying the prevailing price for it. During the irrigating season, which begins about the first of April or May, the city charges $8.00 per day of twenty-four hours for an irrigating head of 100 miners' inches. This rate is changed to $5.00 for a day run of twelve hours, and $3.00 for a night run, to suit the convenience of irrigators.

The four hundred inches now flowing through the company's pipe line is used upon about twenty-two hundred acres of land, devoted mainly to vegetable gardening. After reaching the land to be irrigated, the sewage is conducted from place to place by means of ordinary open earth ditches. This land now pays an annual rental of $12.00 per acre for river water irrigation, under the zanja system, and $18.00 per acre for sewage irrigation. Here is $6.00 per annum in favor of the latter. Further convincing proof of the superior value of sewage for irrigation is furnished by mere inspection of the orchards under the two systems.

This company has found, by experience, that on sandy soil, where the subdrainage is fairly good, it pays to use the sewage during the whole year. When not actually needing the sewage for irrigation, they find it better to flood the land than to permit the sewage to waste. The sandy soil acts on the principle of a strainer, retaining on its surface the coarser fertilizing matter, while the watery fluid portion passes away.

The writer recently visited the sewage farm of Pasadena, which is situated about six miles from the city in a southeasterly direction. This farm has an area of three hundred acres, is of a light, sandy loam soil, and has good natural drainage. An outfall sewer of vitrified clay pipe, 14 to 28 inches in diameter, carries the sewage to the farm, passing through the town of Alhambra.

Pasadena claims a population of about ten thousand, and there are possibly twenty-five hundred sewer connections.

There being no reliable information regarding the amount

of sewage flowing to the farm, the writer estimated it to be about three second-feet, or 150 inches.

Of the three hundred acres, one hundred and forty are in grain and have never been irrigated. Sewage has been used upon the remaining portion, cultivated as follows: Walnut orchard (four years old), sixty acres; alfalfa, twenty-five acres; corn, twenty-five acres; vegetables, potatoes, pumpkins, etc., fifty acres.

This farm has been self-sustaining, the cost of maintenance and revenue being each about $2500 per annum.

The public mind is greatly prejudiced against sewage irrigation, and that this prejudice is due to ignorance rather than to any harmful effects of the process, cannot be successfully denied. The objections made are always fanciful rather than real.

With a very few exceptions, there seems to be no valid objection to the use of sewage for the irrigation and growth of all kinds of agricultural products.

A great deal of "learned nonsense" has been written by theoretical engineers on the subjects of purification of sewage and sewage disposal. The writer believes the experience, here recorded, of successful and profitable sewage irrigation to be a convincing demonstration that the true solution of the problem of sewage disposal for inland towns lies in the application of sewage to irrigation.

In closing, the writer wishes to acknowledge his indebtedness to Mr. C. F. Derby, superintendent of the Outfall Sewer, and to Mr. Henry Martz, president of the South Side Irrigation Company, for courtesies extended.

DISCUSSION.

Mr. James D. Schuyler.—There are so many novel and interesting features in the construction of the Outfall Sewer here described, that the paper must be regarded as a valuable contribution to the literature of engineering on a subject of general interest to the profession.

While the general plan and details of the sewer are subject to criticism, the work cannot be pronounced a failure by any means, as it has a minimum grade of 6.6 feet per mile, and cannot fail to carry the sewage delivered to it, up to its maximum capacity, which does not yet seem to have been reached. In all portions of the work where ordinary, every-day construction details were employed, such as the brick conduit, sewer manholes, brick and concrete-lined tunnels, etc., the workmanship appears to be fault-

less, and it is only in such details as are somewhat out of the usual order that difficulties were encountered pointing to partial failure, as indicated in the paper, viz: in the sand-box or settling chamber; the so-called irrigating hydrant; the "blow-off" (a very remarkable feature to introduce in any sewer, and particularly remarkable as here designed, standing high above the surface and pointing upward like a cannon to fire at the moon); the butterfly throttle valves, which appear to have had no useful purpose, and like the other novelties have been abandoned; and the terminal outfall pipe. As described in the paper, the latter, a cast-iron pipe, originally delivering the sewage into the ocean at a depth of twenty feet, has been broken and partially destroyed, owing to lack of proper protection from ordinary wave action and ocean shore currents. It is difficult to conceive how this pipe could have been expected to take care of itself, laid as it was on the surface of the sloping beach, on unstable sands, without any sort of anchorage to hold it in position. A few iron piles on each side of the pipe, sunk to safe depths, would have kept it in line, and, while the littoral currents might have undermined the pipe by washing the sand from under it, there would have been a somewhat greater probability of security had such piles been driven. The very slight flexibility given to the pipe by the rubber gaskets in the flanged joints would perhaps have been insufficient to have kept the pipe from breaking by local undermining, even had it been kept in line in the manner described, and some of the standard forms of ball and socket joint would appear to have been preferable for this service.

In view of the conspicuous success that has been achieved in the disposal of sewage by irrigation in the European cities, as well as nearer home, the policy of constructing an outfall sewer to the ocean must be regarded as a questionable one, particularly in a country where the soils and the climatic conditions are all so extremely favorable for successful sewage disposal. Within five miles of the city limits a sewage farm could have been secured on land otherwise valueless, because of the very conditions which would render it specially desirable for sewage disposal, viz: a dry, light, porous, top soil, and open, gravelly subsoil affording ready drainage for the effluent. The cost of such a disposal of the city sewage would doubtless have been considerably less than by the present method, and it is to be hoped that in the future growth of the city, when the capacity of the present conduit has been reached, extensions of the system may be made in the line of utilization by irrigation, and the establishment of a sewage farm under city

control, rather than in the duplication of the present sewer to the ocean.

The data given in the paper as to the irrigation from the sewer are of special interest. The total revenue from sewage water sold in 1896 was $4009.50, or $2.59 per acre irrigated, the price at which the water was sold being $8.00 per twenty-four hours' run of 100 miners' inches (2 second-feet). From these data it would appear that the average depth of application must have been about 1.3 feet during the irrigation season. The irrigation rate given by the city to its consumers directly supplied from the sewer, appears to be but 44 per cent. of the rate paid by the farmers to the South Side Irrigation Company, who deal in the article as a business and make it profitable, and one cannot but wonder why the inducement offered by the low rates should not be sufficient to make an active demand for all the sewage flowing, instead of permitting a part of it—about 300 miners' inches at this writing, May 1st—to flow to waste to the ocean. The reason is perhaps to be found in the fact that the land passed over by the Outfall Sewer is, to a considerable extent, held in large tracts, and never having had the advantage of a water supply heretofore, has not the population or the degree of development to be found in the district supplied by the South Side Irrigation Company, which is nearer the city limits, and which has been, in part at least, accustomed to a periodical supply of clean river water from the regular irrigation system of the city, and is a district of small farms.

It is interesting to compare these rates for irrigation water with those prevailing in other localities. For example, the rates under the Bear Valley Irrigation Company's system last year were $35 per 100-inch twenty-four hours' flow; in Covina last year, during an unusual scarcity of supply, as high as $65 was paid for the same volume. At $8.00 per 100 inches the cost is equivalent to about $2.00 per acre-foot. Under the Sweetwater system the present rates are equivalent to about $2.20 per acre-foot, but the company is endeavoring to raise them to double this amount. Under the system of the San Diego Flume Company, the present rates of $60 per miners' inch per annum are equivalent to $4.15 per acre-foot.

The high value ascribed to sewage for irrigation in the district supplied by the South Side Irrigation Company, as described in the paper, as compared with ordinary river water less heavily charged with the elements of plant growth, and the low price at which the city sells the sewage, lead to the expectation that the section of the country favored with so cheap and so valuable a

water supply will not long permit any of it to flow unused to the ocean, and that the demand will, within a short time, keep pace with the supply.

The thanks of the society are due to the author for this entertaining paper, and engineers generally will recognize the fact that a lesson of "how not to do it" is quite as acceptable and instructive as one teaching the reverse.

Mr. H. Hawgood.—The work of which Mr. Bassell's paper treats is one of more than ordinary engineering interest, the use of inverted siphons of over three miles in length being a marked departure from usual sewer construction, and the same may be said of the wooden stave pipe used in this manner. Mr. Hy. Dockweiler and the corps of engineers who so ably assisted him in the design and construction of the works are to be congratulated upon the generally satisfactory result of their labors.

It is to be hoped that the discussion will bring out more details as to the experience of operating these long inverted siphons, particularly as regards the movement through them, or lodgment, of sand, stones and other substances.

The stripping of the $\frac{5}{8}$-inch nuts, mentioned by Mr. Bassell, is in keeping with the general experience of iron-workers; that an ordinary laborer, with an ordinary wrench, can, and usually does, strip or twist off any bolt less than $\frac{3}{4}$-inch diameter. For this reason it is good practice to use nothing less than $\frac{3}{4}$-inch diameter wherever bolts are to be tightened by other than skilled mechanics.

In the matter of vents below the straightway valves, there can be no question as to the utility of the one introduced below structure No. 44A, the outlet of the inverted siphon being five or six feet *below* the gate; but, at structure No. $19\frac{1}{2}$, where the conditions are reversed and where the outlet is some five or six feet *above* the gate, the use of a free vent is questionable, and it would be of interest to hear the reasons that governed its adoption. The paper does not furnish data for anything more than approximate calculations, but it would appear that, with a full sewer and with the gate closed instantaneously, the stored-up energy of the moving body below the gate (in the inverted siphon) would be about 1,880,000 foot-pounds and, before the mass had been brought to rest by the opposing head and friction, some three to four hundred feet of sewer immediately below the gate would have been emptied. This distance will, of course, be reduced by decrease in quantity of flow through the sewer and by slow closing of the gate. After a momentary pause, the water will fall back into this empty space, and, meeting with sudden stoppage at the gate, will cause a severe

"hammer-blow" and great strain on the sewer, as evidenced by the articles mentioned by Mr. Bassell as being ejected from the vent pipe. Undoubtedly, a formidable quantity of accumulated work is suddenly and violently dissipated, to the danger of the sewer. If a vent is used, it certainly should be furnished with a valve, which, while giving free ingress to the air, would check its egress sufficiently to form an efficient air cushion and bring the returning water gently to rest.

In place of a valve, with the resulting complication, it would probably be better to provide no vent, and to arrange for a positively slow closing valve. Any tendency to the formation of a partial vacuum below the gate tends to increase the effective head opposing the movement of the water column, and at the same time increases the discharge through the gate opening to destroy the vacuum. Properly carried out, it would subject the sewer to no greater strains than a controlled vent, and certainly less than the present free vent. Parallel cases are to be found on almost every large water main.

In regard to the breaking of Lateral No. 1, I can speak advisedly as to the causes of failure, having been called in to advise as to repairs. The primary cause of failure was weak design. The sides of the aqueduct were of insufficient strength to resist bursting with a full conduit, even with a perfect bond between the sides and floor, and in many places this bond was imperfect, for the arch ribs of the structure formed a channel under the floor. The form which filled this channel, and which formed part of the mold for forming the concrete was of wood. The wet concrete swelled the wood, and that, in its turn, thrust upon the sides and prevented any bond between sides and floor. In the rebuilt structure this danger was avoided. The hooping of the structure with rails was to strengthen work built under the original design, that had not actually failed, but was dangerous under a full head. The concrete specified as 7 to 1 was good, for that mixture; showing a crushing strength of over nine hundred pounds per square inch.

Mr. D. C. Henny.—The design of the details of the wooden pipe siphons deviated from ordinary wooden pipe practice. *First*, in the use of wooden instead of metal tongues for connecting the butt-ends of the staves; *second*, in the form of the shoes uniting the ends of the steel bands: and, *third*, in the absence of an upset and in the fine thread on the bands.

The first deviation seems objectionable, because the comparatively great thickness of the wooden tongue precludes the possibility of indentation at the bottom of the groove. The depth of

the groove must therefore be exactly one-half the width of the tongue, in order that the staves may butt up tight and at the same time the groove be completely filled by the tongue. Such exact fit is not uniformly possible with ordinary wood-working machinery, and the tendency is to have the slot too deep, in order to insure the solid butting up of the staves. Thus the hard contact at the bottom of the groove, caused by positive indentation of a metal tongue, is not attained; and, moreover, vacant spaces may be left, back of the tongue, which in themselves are objectionable, as they may cause leakage by being filled from the inside at one point of accidental defect, and may connect with the outside at another such point. The thick projections of the tongues beyond the edges of the staves may also prevent the adjoining staves from coming to as perfect a bearing as is desirable, at least where the spacing of the bands is wide. It appears, however, that no trouble has resulted from this cause.

As regards the second deviation, the objectionable features of the form of the shoes have been pointed out by the author. By adding length and thickness, this form of shoe can undoubtedly be made strong enough to resist the torsional strain to which it is subjected, but the writer has never seen any shoe of this type where this had been done to a sufficient extent. In the case under consideration, this weak point became more apparent, as the material used was common cast iron. Malleable iron or steel is preferable, for no shoe can be designed in which a portion of the metal is not in tension.

Respecting the third point, the writer holds that great waste results from cutting the threads on pipe bands, instead of rolling them on, or instead of previously upsetting the ends. It was probably with a view to reducing this waste that a much finer thread than the standard was used. Experience has evolved certain proportions of threads, in harmony with average accuracy of shopwork, and merely theoretical reasons hardly justify one in departing from these proportions. That frequent stripping of threads occurred in cinching, as stated by the author, was not surprising. With good work in rolling or cutting threads and tapping nuts to standard proportions, continued turning of the nut will, in the large majority of cases, result in rupture of the bolt by the combined effect of pull and torsion, and not in stripping of the thread.

Considering that the points of greatest depression in the two inverted siphons are but twenty-seven and twenty-five feet respectively below the hydraulic grade line, and that the fluid carried was

FIGS. 7 AND 8.
BREAK IN LATERAL NO. 1.

sewage and not clear water, the leakage that was first experienced after filling, and which necessitated the subsequent digging up of most of the entire pipe line, was a surprise to the writer. It is true that both the contractors and their men lacked all experience in wooden pipe construction, but there was honest and rigid inspection on the part of the city. Whether poor workmanship was alone responsible for the result may be doubted. The author has described the butterfly valves which were placed at the lower ends of the siphons to maintain the upper ends full. Although they are stated to have leaked badly when closed, they must at such times have come near converting the hydraulic head on the siphons to a hydrostatic head, thereby increasing the head on the lower ends of the siphons about twenty-five feet. The bands on the pipe were not spaced sufficiently close for this additional head, even neglecting the serious water hammer which might be looked for from the operation of these gates.

The use of butterfly valves on long pipe lines with high velocities is, in the writer's opinion, radically wrong, as it usually permits too rapid operation and the valves cannot be made tight. Possibly the author can give some information on the occurrence of water hammer at the time these gates were in use. The slide valve, besides being tight, has the advantage of being more readily adapted to extremely slow motion. The quick closing of gates should be a physical impossibility on long pipe lines with high velocities of flow, for it is far better to prevent serious water hammer than to attempt to neutralize its evil effects by automatic devices. An open air vent, back of a main gate, is very desirable, but it should not be depended upon to render too rapid obstruction of flow harmless beyond preventing collapse.

The location of the new slide valve gates on the upper stretches of the siphons approximately on a level with the outlets, is preferable to that of the old butterfly valves at the outlets themselves, as they attain the same object with a minimum increase of pressure on the pipe when closed.

Before the system was put in operation some fear was entertained lest the sediment formed in the pipe at times of small discharge would not be flushed out at times of maximum discharge. The writer understands that there has been no trouble in keeping the pipe clean, but, in view of the author's statement that the settling basin at the upper end permits the bulk of the suspended matter to pass on, some definite information on this point and on the maximum velocity of flow, at present available for flushing, would undoubtedly prove of interest.

Mr. Gervaise Purcell.—Being unfamiliar with the details of the Outfall Sewer, I am unable to give an opinion as to the justness or unjustness of the criticisms, as local circumstances have to be taken into account.

On the use of sewage for farm purposes, where the land is suitable or has been suitably prepared, I have always been a strong advocate of broad irrigation, feeling that the experiences of the sewage farms of Berlin and other cities of Europe, place it beyond the pale of experiment.

In November of 1894, I was consulted by the city of Pasadena as to the best way to remodel its sewage farm so as to abate the nuisances into which it had drifted, and to make it self-sustaining if possible. Hence I am able to verify the author's statement as to its present condition, only correcting him so far as to say that last year it showed a balance in its favor of $600; and, as the walnuts come into bearing, this balance will increase from year to year. I found that, to make the sewage flow freely, so as to be kept in sufficient motion to prevent stagnation, which might create a nuisance, it is necessary, in this climate, to dilute the sewage with an equal amount of water, and that this is best accomplished in the main conduit as it flows to the farm. The author is in error as to the amount of sewage, it being only half a cubic foot per second for the three thousand connections reported. This, with as much water added, gives a constant summer flow of one cubic foot per second. It was liberally prophesied that the product of the farm would never find a market, but, as a fact, from the first the demand has exceeded the supply.

Mr. Grunsky (Temporary Chairman).—The use of an inverted siphon on a large scale, in connection with a sewerage system, has been brought out very nicely and clearly in this paper. Notwithstanding that mistakes were made in some of the details, the entire system seems to be operating fairly well.

The paper itself and the written discussions that have been read cover the points quite completely. There is, however, one thing in connection with this sewer that is not mentioned in the paper nor in the discussions. The original question presented by the city of Los Angeles to the engineers was as to the best method of disposing of the sewage, whether to carry it out into the ocean, or whether to use it for sewage irrigation. The result was that a line was so constructed that the sewage can be used for irrigation, or it can be emptied into the ocean. Either method can be used.

Mr. Allardt.—Why was not a wooden pipe used all the way? It would be cheaper than anything else, and it is strong and admits of a very rapid current.

Mr. Henny.—There were places that required a stronger material than wood, and in such places they used other material.

Mr. Allardt.—Could not the grade line be made in such a manner that the pipe would be full all the time?

Mr. Henny.—Probably the depression was such that the use of a siphon could not be avoided.

Question.—Is the velocity given, or the grade?

Mr. Grunsky.—It is stated in the paper in a general way. Of course, the discharge of the sewer is variable, as a large amount of sewage is sometimes used for irrigation.

Mr. Henny.—I think the system has been laid out for a much larger flow than there is at present.

Mr. Wagoner.—Has there been any trouble with leakage in the wooden pipe portion of the sewer?

Mr. Henny.—There was some leakage, which seemed to be all along in the seam joints; possibly more where the butt joins than elsewhere. The general cause of leakage was in not cinching the hoops sufficiently tight. The castings would break, and there was stripping of threads when the hoops were cinched tightly, and this extra expense the contractors did not like to bear, not seeing the actual necessity of it.

Mr. d'Erlach.—You stated, I believe, that the hoops were some distance apart?

Mr. Henny.—I think about twelve inches—possibly ten inches.

Mr. Allardt.—Would not the acids in the sewer hasten the rusting of the iron hoops if it percolated through the wood? It is more corrosive than pure water.

Mr. Henny.—Of course, the wood will act to a certain extent as a filter. The percolation through the wood would be very small. As to the condition of the sewage after it had filtered through an inch and a half of wood, I am not prepared to say.

Mr. Allardt.—The corrosive action would be a great deal more than if it were pure water.

Mr. Henny.—There would be more acid in it.

Mr. Storey.—Was this sewer constructed on the idea that it was an improvement on the general plan pursued in other systems?

Mr. Henny.—Yes; but I would not be understood as saying that it would not have worked properly under other systems.

Mr. Storey.—I do not see why it should work any better than other methods.

BRADLEY & POATES, ENGR'S N.Y


PLATE 1
MAP
OF THE
Outfall Sewer
Of the City of Los Angeles, Cal.
J.H. Dockweiler, City Engineer.
Scales
5000
10,000 FEET
500
1000
2000
3000 METERS
Note - Miles denoted thus -
Pacific
Ocean
City of Los Angeles
D. FREEMAN TO LOS ANGELES CITY
City Lands
CENTER LINE OF OUTFALL SEWER
SECTION 9
SECTION 8
SECTION 7
SECTION 6
SECTION 5
SECTION 4
SECTION 3
SECTION 2
SECTION 1
T. 2 S. R. 15 W.
T. 3 S. R. 15 W.
T. 2 S. R. 14 W.
T. 3 S. R. 14 W.
T. 2 S. R. 13 W.
LATERAL No. 1
LATERAL No. 2
LATERAL No. 3
Beginning of Lateral No. 1
Beginning of Lateral No. 2
Beginning of Lateral No. 3
End of Lateral No. 1
End of Lateral No. 2
End of Lateral No. 3
Inglewood
Hyde Park
SOUTHERN CALIFORNIA R.R.
BALLONA AVE.
WESTERN AVE.
VERNON AVE.
VERMONT AVE.
SANTA MONICA
WEST BOUNDARY
SOUTH CHARTER BOUNDARY
AGRICULTURAL PARK
FIGUEROA
TUNNEL


MAP

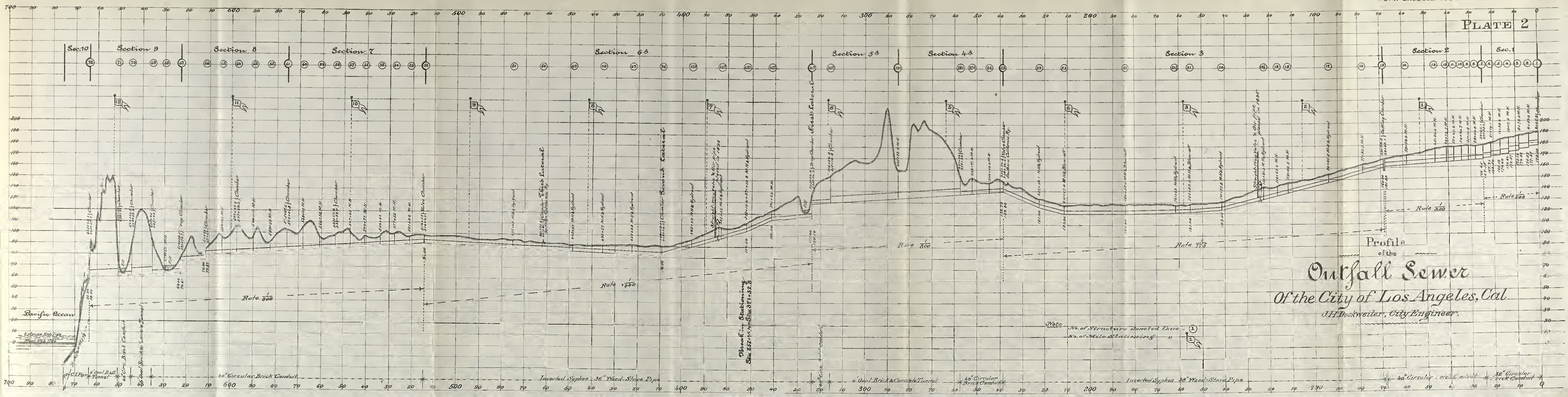


PLATE 2
Profile
of the
Outfall Sewer
Of the City of Los Angeles, Cal.
J.H. Dockweiler, City Engineer.
Sec. 10
Section 9
Section 8
Section 7
Section 6A
Section 5A
Section 4A
Section 3
Section 2
Sec. 1
Pacific Ocean
Rate 1/300
Rate 1/440
Rate 1/800
Rate 1/775
Rate 1/500
Third Lateral
Second Lateral
First Lateral
40" Circular Brick Conduit
Inverted Syphon 36" Wood-Stave Pipe
6' Oval Brick & Concrete Tunnel
40" Circular Brick Conduit
Inverted Syphon 38" Wood-Stave Pipe
40" Circular Brick Conduit
38" Circular Brick Conduit

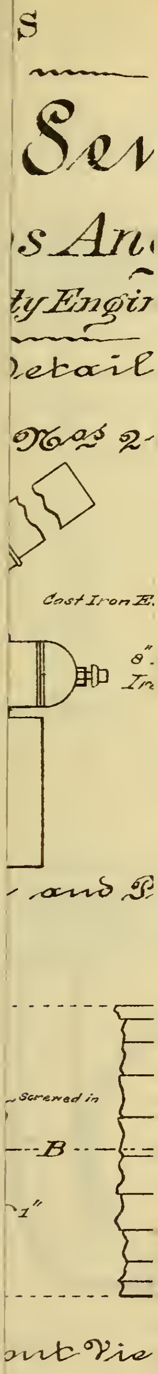
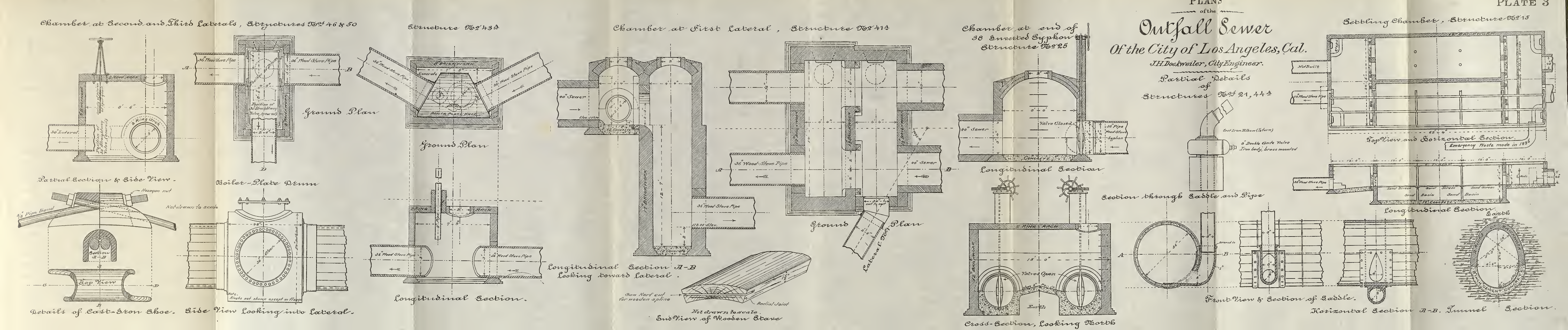

s
Sew
s An
tyEngin
etail
Nos 2-
Cast Iron E.
8"
In
and B
Screwed in
B
1"
nt Vie

PLATE 3


Plans
of the
Outfall Sewer
Of the City of Los Angeles, Cal.
J. H. Dockweiler, City Engineer.
Partial Details
of
Structures Nos 21, 44A
Chamber at Second and Third Laterals, Structures Nos 46 & 50
Partial Section & Side View.
Ground Plan
Boiler-Plate Drum
Details of Cast-Iron Shoe.
Side View Looking into Lateral.
Structure No 43A
Ground Plan
Longitudinal Section.
Chamber at First Lateral, Structure No 41A
Longitudinal Section A-B Looking toward Lateral.
Ground Plan
Not drawn to scale.
End View of Wooden Stave
Chamber at end of 38 Inverted Syphon Structure No 25
Longitudinal Section
Section through Saddle and Pipe
Cross-Section, Looking North
Settling Chamber, Structure No 15
Top View and Horizontal Section.
Emergency Waste made in 1896
Longitudinal Section
Front View & Section of Saddle.
Horizontal Section A-B.
Tunnel Section.

Editors reprinting articles from this journal are requested to credit both the JOURNAL and the Society before which such articles were read.

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CONDUITS AND CABLES.

BY ALEX. DOW, MEMBER DETROIT ENGINEERING SOCIETY.

[Read before the Society, December 18, 1896.*]

A CONDUIT may be defined as a passage or subway for containing electric wires, underground cables, or the like. In a more limited sense, a conduit is a tube or channel into which such conductors may be placed or drawn, but which is not itself accessible for inspection or repair of the conductors, as distinguished from a subway, into which access can be had at any portion of its course.

An instance of a conduit in the narrower sense is a tube, having manholes at different points along its length, the conductors being pulled into the tubes by ropes passing from one manhole to the other; while an instance of a subway would be a tunnel of dimensions to admit of the free passage of men and of the use of tools for any of the common operations required on the conductors.

The former construction is common through the United States; the latter is exceptional, the only city where any systematic subway work has yet been completed being St. Paul, Minn., where local conditions make a tunnel construction less expensive than a conduit of any but the smallest capacity.

The history of conduits begins along with the practical use of electric telegraphs. The plans of Professor Morse included a lead pipe conduit into which an insulated wire was to be drawn.

*Manuscript received September 3, 1897.—Secretary, Ass'n of Eng. Socs.

and this construction was begun on the experimental Washington-Baltimore line, but failed almost at once through mechanical defects. Wires, strung on posts, were substituted, and were used without protest in the largest American cities, as well as along railroads and highways, until within the last few years. But on the other side of the Atlantic the public objection to the obstruction and disfigurement of the streets by posts and wires was strong enough to force a different solution of the problem, and the opportune discovery of the qualities of gutta-percha as an insulator for electric conductors presented the means; so that the first city telegraph office in London was connected to the railroad telegraph wires by gutta-percha insulated wires drawn into iron pipe, a combination which is standard for telegraphic work in Great Britain till to-day, the pipes being invariably cast-iron and the wire being sometimes, for mechanical reasons, insulated with india-rubber instead of gutta-percha.

It was very much later before the American telegraph companies were obliged to place any of their wires underground, and the experience of British and European telegraph departments was then available to guide them. Gutta-percha insulated wires were imported, and at least one factory for the making of such wires was established here; but by this time the manufacture of india-rubber had been developed to such an extent in the United States that cables insulated with this latter material could be produced cheaper than those of gutta-percha, and so became standard, as far as anything (with one notable exception) ever has become standard in American cable practice.

The introduction of electric lighting, twenty years ago, brought with it a new set of conditions. The amount of power to be carried by an electric lighting conductor was infinitely greater than that on any telegraph wire. The heating effects of large currents, which were entirely unknown in telegraph practice, had to be considered; and the fact that electrical supply had to be furnished to a large proportion of the buildings in a city introduced problems as to connections and branches which were radically different from anything found in telegraphic work. It is evident that a system of telegraph cables to connect with four or five, or possibly a score of offices, in one city was a very different thing from a system of electric lighting cables to connect with several thousand different customers. This last condition was at first much the most difficult to meet, because neither the stress due to high electric potential nor the heating due to large currents was, in the earliest electric lighting, much beyond

the limits which had been reached in telegraphic work; indeed, in England, some early distributions of electric light were made with entire success through conductors insulated with vulcanized india-rubber, after the same specification as conductors for telegraph purposes. In these instances the pressure was not in excess of 100 volts.

The development of cables and conduits in British practice has been mainly on the line of telegraphic work, and even in this present year electric lighting plants are being installed in Britain in which the cast-iron pipes forming the conduits have been furnished under specifications identical with those used by the British Post Office for pipes for telegraph purposes, and the rubber-insulated cables differ only from the wires furnished to the post office in having greater cross-section of conductor and increased thickness of the rubber walls.

But in the United States the public had been educated into the toleration of overhead wires, and our cities were disfigured within five years with a forest of posts and a network of aërial conductors more extensive and more offensive than all the telegraph wires strung in the preceding forty years. Only one electrical inventor, Mr. Edison, spared the time to design a complete system of buried conductors for electric lighting currents, and only the Edison lighting companies were willing, under his advice, to meet the expense of laying down complete underground distributions. The system Mr. Edison designed fulfilled admirably the requirements I have just stated, and, most admirably of all, that of permitting, without interruption of current or weakening of insulation, the frequent connections of service wires for customers. How much this design was in advance of current practice is shown by the record in this city, where the Edison mains laid in 1886 have remained in continuous service till to-day, while no other electrical supply company has yet constructed an effective system of underground mains, and the city's underground mains for street lighting were only put in service last year.

In the lighting department are to be found the greatest variety of conduit and cable constructions and the most complete absence of a standard practice. Even the Edison companies in these latter days have followed strange prophets. Very false prophets, too, have some of them been.

The telephone followed closely on the electric light in its early development, and it also had its period of overhead wires and street obstruction and disfigurement. It has, however, redeemed itself early in the day, and the gigantic poles, carrying

hundreds of telephone wires, have disappeared from the business districts of all our large cities.

Telephone practice in cables and conduits was at first a copy of the existing telegraph practice, but the scientific study of the telephone carried on under the auspices of the Bell Telephone Company has led to a differentiation in the direction of the use of cables better suited electrically to telephonic currents of small volume and of very high frequency, and better suited mechanically to the conditions which require many thousands of independent conductors to be concentrated within the smallest possible area in the conduits leading to a modern telephone exchange. This is the notable instance of standardization to which I have previously referred.

The modern telephone cable, called the "conference cable," represents the practical experience, the laboratory experiments, and the mathematical calculations of as competent a corps of engineers as can be found in the United States to-day.

To give a history of all the developments of my subject is a task that is far beyond the limitations of a paper like this. The best that can be done is to describe the practice of the present day and to state shortly the reasons of this practice.

Conduits for all systems of electric distributions are governed alike by some conditions. They must, in common with all underground structures, be of material that will not decay in the presence of moisture and of the various destructive agents found in the soil. Among these destructive agents are included the illuminating gas with which the subsoil of most of our cities is saturated, the leakage from sewers and cesspools, and the electrolytic action of the return currents of the street railway system. Further, the conduit must resist the settling of the soil and the bad usage by careless laborers which accompany the frequent excavations made in city streets. Lastly, it must be intersected at convenient points by distributing chambers, commonly called manholes. In addition to these *absolute* requirements, the conduit should preferably be drained and ventilated, so that there will not be in it any accumulation of water or gas to interfere with the operations of workmen having business with the cables. In a system designed to be water- and air-tight these latter requirements are not necessary, so that I have indicated them as desirable rather than absolute conditions. You will notice that I say "water-tight and air-tight." It has been frequently assumed by inventors, and occasionally by skilled constructors of conduits, that a conduit might be made water-tight

without being absolutely air-tight. I am satisfied that if the former condition is sought, both must be secured, because air carries with it a certain amount of moisture and will, on a reduction of temperature, deposit that moisture on any hygroscopic surface with which it is in contact. In my experience I have never seen a water-tight or so-called "weather-tight" construction, not also air-tight, which did not sweat very badly, and even sealed junction boxes and switch boxes, which are only occasionally opened to the atmosphere, will be found to suffer to a slight extent from the same trouble.

It is in order here to discuss the differences between the two classes of conduits,—those which are intentionally made air- and water-tight, and the much larger class in which there is no special endeavor made to secure tightness. The first class is usually an insulated conduit,—that is to say, the conduit construction is itself of insulating material and the conductors are either bare or only covered for mechanical reasons. The insulated conduit has been a dream of hundreds of electricians, and has been sought for persistently from the earliest days of the telegraph. I believe that but two systems have yet been developed which have stood the test of time and can now be classed as successes. The first of these is much in use in England and, to some extent, on the continent. It is not the production of any one inventor, and although many of its details, as used in different installations, are covered by patents, the method as a whole is open to any user and details of a practicable kind can be designed by any good engineer. It is generally known as the "Crompton" system. A conduit, usually of concrete, but sometimes of brick or iron, is constructed in lengths as long as convenient, subject to the limitation that each length must be straight in both the horizontal and the vertical plane. In this conduit are placed porcelain insulators of a saddle or tube shape, over or through which are drawn copper rods or strips. At each change of direction, and at intervals in any straight run of exceptional length, small vaults are built, having air-tight covers, and in these vaults clamps to grasp firmly each conductor are placed, and a screw and nut or equivalent device attached to each clamp wherewith to strain the conductor, so that it does not sag between insulators. In some instances automatic devices are used for taking up any slack due to heating of the conductors, but the more common practice is to apply sufficient initial tension to prevent the copper sagging to a dangerous extent under the maximum heating that is to be allowed.

I do not know that this method has ever been applied to

conductors having a potential difference greater than 500 volts. Its continued use proves that it must be a success, but it has developed some characteristic faults. First, there is the sweating, which I have already mentioned. The air trapped in the conduit will, on a fall of temperature, deposit its moisture on the porcelain insulators, and the wooden blocks on which these insulators have been mounted are found in time to become saturated with water. This produces a state of permanent dampness in the conduit, causing a slight general leakage of current, and if the trouble stops at this there is little fault to find, as in the low-tension systems such a leakage is not very expensive.

But the gases which saturate the soil also find entrance to the conduit, and the distilled water of condensation absorbs these gases, so that the leakage is aggravated by the change from *aqua pura* to an aqueous solution of one or more objectionable chemicals, and surface leakages of large quantity become normal, with electrolytic deposition of copper salts on the porcelain. It was believed at one time that the porcelain surface was permanent, but now one user of this system is seriously considering the abandonment of it entirely, because of the impossibility of cleaning or replacing the porcelains as frequently as is required, and because the compounds electrolytically formed are held to have been responsible for explosions of the mixture of air and gas in the conduit.

The other system which has proved a success is one developed by a Detroit inventor, Mr. Cummings. He placed on the market some four years ago tubes into which bare copper conductors could be drawn readily, in lengths up to 300 or 400 feet, and of sizes up to 1 square inch of cross-section. To about $\frac{1}{6}$ of a square inch these conductors may be round copper rod, the size known as 4–0 Brown & Sharp gauge being frequently used. Above that cross-section the conductor must be stranded. The tubes are made both single duct and multiple duct, as many as seven ducts having been used in local practice. The outer tube is iron, usually being standard weight steam pipe. The ducts are wooden tubes, the wood being treated with creosote or some similar preparation in order to secure durability. In the single duct form for low voltages the wooden tube is directly in contact with the iron tube, but when the single duct is used for conductors of higher electro-motive force, and when multiple ducts are used, the wooden ducts are served with cord, which acts as a mechanical separator from the iron pipe and also to separate one duct from another, and the interstices are filled with a mineral product,

such as asphaltum or tar. The material at present used for filling is one of the petroleum products. These completed tubes are butted together, end to end, the exact coincidence of each duct with its continuation in the next tube being secured by very simple means, and this butted junction is made water- and air-tight by clamping around it a cast-iron box, which is filled with compound similar to that used in the tubes. The manholes or junction boxes of this system are iron castings, with loose outer cover and an inner cover which is made tight by a rubber gasket and an application of hot beeswax and tallow.

The Cummings system has a number of advantages peculiar to itself. The wood surface of the duct is not hygroscopic, so that no condensation takes place except on the sides of the iron manholes, where it does no harm.

The coefficient of friction between copper and the prepared wood is very small, so that there is no trouble in pulling a great length of heavy conductor. Then the material seems to be permanent in its electrical and mechanical qualities, and it is of necessity used of considerable thickness, so that there is no possibility of conductors in different ducts being brought within the sparking distance of any ordinary voltage. I don't think that the makers of this conduit will err as did the cable manufacturers in placing cables on the market which gave a high laboratory test, but infallibly punched out under the practical conditions of use.

There have been several attempts made by manufacturers of paper-lined tubes to introduce these into service as underground conduits. So far I do not know of any permanent success. There was one very rank failure in this city, of which most of you who observe such things are probably cognizant. A conduit system was laid of paper tubes stacked in a box filled with roofing tar and having manholes which were *supposed* to be water- and air-tight. Into the tubes were drawn wires braided or lightly insulated with rubber tape. It was a mistake to insulate the wires at all, because the braiding received moisture from the air at each reduction of temperature, and held it in contact with the paper of the ducts. The surface of the paper was moisture-resisting, but the material was not so saturated as to be permanently damp-proof, and in due time there were frequent failures of insulation and burning of the conduit. Please note that it is a good thing (other things being equal) to have your duct material fireproof, because if anything does go wrong with an electric light conductor a blaze is the usual consequence. The troubles which were

incident to the design were aggravated by the carelessness of the builders, who made many connections into the manholes in a rough-and-ready way, which was certain in time to allow the entrance of water to these manholes, and from them to the tubes. Finally the system, after suffering still more from neglect of men who should have taken care of it, was abandoned altogether.

I don't know any reason why a paper tube system should not be brought into practical shape. It is still being exploited occasionally by one tube manufacturing concern, and they may ultimately make it a go. Their circulars, however, distributed within the current year, show a lack of appreciation of the practical conditions of conduit work which prevents my hoping for an early success.

There is a tight system occasionally used which deserves mention, although its limitations are such as to prevent its general adoption. It is the Brooks oil-insulated conduit. In this method an iron pipe is laid and made tight. Into it the conductor, wrapped with a fibrous covering, such as jute, is drawn, and finally the tube is pumped full of heavy oil, such as resin oil. Arrangements are made so that a pressure of a few pounds to the square inch is maintained on the oil, so that there is no tendency for water to leak in and displace it. A very perfect system of glands and packing has been devised for service connections and terminals. The chief claim made for this system is that the oil prevents the development of a permanent fault sequent to a high-tension discharge from the conductor to the iron pipes. Experience in this country with oil-insulated transformers would justify this claim, but it is doubtful whether under any usual conditions the complications of the system would be warranted in order to secure this special advantage.

Coming now to the much more common conduit systems, which are neither tight nor insulated—which are tersely described by a practical man as "horizontal holes in the ground into which you can pull cables"—the tendency to-day is to accept as standard for all classes of electrical work a duct of vitrified brick or terra cotta. There is a strong minority opinion in favor of a duct called "cement-lined," molded within a sheet-iron shell from a mixture of Portland cement and sand,—an artificial stone. The fault of the latter is its very high coefficient of friction in conjunction with the usual lead sheathing of cables, which makes the pulling of the cable through a cement-lined duct a much greater undertaking than through an equal length of tile. The advantage of the cement-lined duct is that it can be produced in greater

lengths than is possible with tile or terra cotta, because of the warping of the latter in the kilns.

Ducts of asphaltic concrete were once used, these having been the earliest in the market, and, having been cleverly exploited, were laid down in many cities, including Detroit. They were expensive, which is their chief fault. The minor faults were liability to damage from the burning out of a cable and from proximity to steam pipes or other sources of heat to be found under city streets.

The tile ducts are made both single duct and multiple duct. Both the Camp single duct tile and the McRoy multiple duct terra cotta conduit have been largely used in this city. For multiple duct conduit the Camp tile is laid in tiers in cement mortar exactly like bricks in a wall, the matching of the ducts being secured by drawing a mandrel into each tile as it is laid. The McRoy conduit is usually laid the same way, but sometimes, when it is important to exclude water, the joints between sections are sealed by a wrapping of jute bagging, saturated with hot asphalt. This is an old plan, having been used with the Lynch conduit, which was a tile of square cross-section (usually 10 x 10 inches), having a horizontal partition, which carried one layer of cables, while a second layer rested on the bottom of the tile.

The standard duct for telephone purposes is 3 inches in diameter, and electric light men are finding this also a convenient size, so that it is now the most frequently called for. It holds three or four small cables or one large one, or a multiple conductor feeder cable for a three-wire system, very conveniently.

Manholes are almost always built of brick. When a fairly large manhole is needed it is hardly possible to use anything but brick. Cast-iron manholes of small sizes can sometimes be placed, but the inflexibility of this material makes it very inconvenient when the street is crowded with pipes and conduits having prior right of way. I have seen and used concrete manholes, some of them of large size, but the same difficulty affects these, as they must be rammed up around a mold, which mold cannot be placed in position if there is any obstruction in the hole. If you have to build a new mold for every hole, there is no profit in concrete work; but with brick you can build the manhole of any shape required, and you may write it down that no two manholes in a city job built in these latter days will have the same dimensions, and you will be fortunate indeed if one-half of them are so nearly of contract shape that the contractor will not claim "extras" on them.

The sewer connection is necessary in manholes frequently used. Those seldom opened and far from sewers may be allowed to fill up with water, if the cables are of the lead-covered type, as pumping out occasionally will be cheaper, in the long run, than sewer connections. Ventilation sufficient for the dilution of gases to a safe figure can usually be had by perforation of the manhole cover, but where much gas leaks in, special provision for ventilation should be made.

The best practice, as exemplified in recent work, is to lay the tile conduits on a foundation of concrete and to fill the space between the stack of tiles and the sides of the ditch with grout. The use of the foundation is obvious. The side filling is preferred to back filling the earth, because it does not require to be rammed, and so the danger of displacing the tiles from their alignment is avoided. On top of the whole construction a layer of concrete is advisable, although not always necessary, its use being to protect the tile from picks and bars in the hands of careless excavators.

There is no standard practice in the construction of branches from main lines of conduits. The telephone companies commonly use sewer tile, employing the usual sweep bends for angles. The joints between the sewer tiles are made with cement mortar. Where there is risk of disturbance, or where the space for the branch conduit is limited, as it is in many alleys and courts, wrought-iron pipe is used. There is a tendency to use cast iron, which I think is preferable to either wrought iron or tile for runs of one or two ducts, in that it is neither so easily injured as the tile, nor does it rust out, nor be eaten by electrolysis, so soon as the wrought-iron pipe. Most of the wrought-iron pipe on the market to-day is not iron at all, but is steel, and it does not last underground as long even as the old-time wrought iron.

In two recent installations of single duct conduits in parks, namely: the West Park plant, in Chicago, and in our own Island Park, wooden pump logs have been used for ducts. This material, when kept constantly wet, lasts for a very long time and is a very satisfactory conduit. In soils which are only moderately damp the saturation of the wood with creosote much increases its useful life. From my experience in Chicago, I should fear that the pump log laid close to the surface, as it is in the West Park installation, will not last for any length of time, but on Belle Isle, where the soil is not only saturated with water, but where the wood has been creosoted, I think the conduit will be as durable as any other material except tile. The objection to tile is the

difficulty of joining it in a wet ditch, such as is usual on the island, the cement being washed out of the joint at once, and the certainty that tree roots, particularly those of the willow species, would find their way into the conduit and in time fill the ducts with a vegetable network, which would prevent the drawing in or out of cables. The creosoted wood is not touched by tree roots at all, and the joints, having been sealed with roofing tar, will permit no access of the suckers.

My idea of a perfect single duct system is a cast-iron pipe laid exactly as is a water main, the joints leaded and caulked and the occasional curves or large radius being obtained, as they are in water main practice, by offsetting each length of pipe a little. It would be necessary to ream out the spigot end of each length of pipe, and there should be provided plenty of flanged lengths to be used instead of the leaded joints in working through occasional wet places. The pipe ought to be thoroughly cleaned at the foundry and coated hot with Angus-Smith compound. Special sweep fittings would be used for laterals entering buildings or led up poles.

To turn from conduits to cables: In all departments of electrical work the lead-covered cable is now used. There are very few engineers laying cables not protected by lead these days. Some estimable gentlemen have been so "rattled" by the ravages of electrolysis that they have advocated a return to the use of non-leaded cables, substituting for the lead a saturated braid or tape. I have not heard anything of this idea for the last eight months, and its advocates have had the worst of it in all the arguments of the earlier part of the year. But this agitation has had the good effect of bringing about the study of the use of protective braids or coatings to be applied over the lead, and it has been found, as usual in our cable practice, that the European engineers have developed this system very thoroughly. Any of the cable companies will now furnish leaded cables having an external coating. One of the best of these consists of, first, the coating of the cable with an asphaltum compound, which does not harden in cold weather; next, the lapping around the cable on top of this coating of a double layer of dry manilla paper; third, another coat of asphaltum, of a different composition, which sets harder than the first coat; finally, two servings of jute twine, saturated with asphalt, the second serving being applied in the reverse direction to the first one. This process, when carefully carried out, forms an ideal protection from electrolytic action. It is important to see that the twine is saturated before it is applied to the lead, as

many cable manufacturers serve the lead with dry twine and attempt to saturate it afterward, which process is almost certain to fail of its object.

The telephone companies, as I have already mentioned, have adopted a standard cable, called the "conference cable." This contains a sufficient number of pairs of small wires, usually 100 pairs, each pair being twisted on itself and the total number being made up into a loose strand. The insulation of the individual wire is a loosely applied strip of paper, dried by heat, but not filled in any way to prevent absorption of moisture. The lead sheath is forced by a continuous process over the strand of twisted pairs, and the ends of each length are sealed against the entrance of moisture by a filling of paraffine and a lead cap, which remains in position until the cable has to be jointed to the next length. Of course, a perforation of the lead would admit moisture to the cable, and, as the atmospheric moisture present on an ordinary damp day is quickly absorbed by the dry paper, very great care has to be taken to maintain the integrity of the lead sheath. The lead is not pure, but is alloyed with 2 or 3 per cent. of tin, which makes it considerably harder and less liable to stretch during the process of pulling in through the ducts. This alloy of lead and tin is almost universally used by American cablemakers. One maker prefers a pure lead with a surface coating of tin applied to it after the cable is otherwise complete. I don't find that this method is any better than the more common one.

The telegraph companies on their main lines have taken lately to using paper-insulated cables, not differing materially from those designed for telephone work, but most of the telegraph cables now underground are rubber insulated, the different wires being bunched under a tape and braid, and in all the later practice having the lead sheath over all. Telegraph cables for submarine work are always rubber insulated in American practice. The Atlantic cables and other long-distance cables are not made in American factories, and are, except when laid in tropical seas, insulated with gutta-percha. The usual finish of a submarine cable is a bedding of tanned jute, with an armoring of galvanized iron wires over all. Cables laid in water infested by the *teredo navalis* are sometimes protected by a copper or brass strip instead of the galvanized iron wires. Bunched cables for use by the American telegraph companies under rivers and estuaries have of late years been lead-sheathed over the bunch of rubber-insulated wires and before application of the jute bedding. The telephone companies avoid submarine cables as much as possible,

because of the bad effects of such cables on the talking capacity of the lines. When compelled to install them they usually follow telegraph practice.

Electric light practice to-day is about evenly divided between paper-insulated cables and rubber-insulated cables, both lead covered. The paper cable for electric light work differs altogether from that for telegraphic work, in that the paper is laid on closely and is saturated with a viscous compound. The paper is not laid on very tightly; the different layers are so disposed as to allow of a slight slip when the cable is bent, so preventing breaking of the paper, because it is necessary to avoid the presence of any cracks or crevice, extending from the copper of the conductor to the lead sheath. Such breaks in the continuity of the insulation are weak points, permitting the passage of high potential discharges, which would be withstood by the body of the insulation. The viscous filling has for its object the restoration of continuity by the slow movement of the filling into any crevice that may form. You will notice that in an electric light cable with paper insulation the paper is a true insulator, while in the telephone cable the paper simply serves to preserve the distance between the individual wires, and the air is the insulator. Rubber cables are preferred for high-tension work—5000 volts and upward—in our practice, although there are theoretical reasons in favor of paper. Only one of the numerous fibrous insulations with which the market was once filled now remains in the market. That is the Waring "ozite" filled cable, which has excellent mechanical qualities combined with a low cost. The other fibrous insulations have been displaced by paper. In choosing between rubber and paper insulation two considerations must be taken into account which are too frequently overlooked. The first is the possibility of the lead sheathing, on which the insulation of a paper-covered conductor finally depends, being destroyed by electrolysis. If electrolytic action is known to exist in the earth where the cable is to be laid, of course the lead should be protected in the first place, no matter what the insulation may be. But if the risk is only a remote one, liable to follow on future extensions of street railway lines, it is well to note that a rubber-insulated cable may continue in use long after the lead is perforated or destroyed. The other consideration, which some engineer or other of my acquaintance overlooks at least once a year, is that with high electro-motive force a definite space must be occupied by insulation all around the conductor to prevent what is called "punching-out"—that is to say, the passage of a

discharge from conductor to lead sheath, so that in many cases it is better to use a greater thickness of the cheaper insulation,—to wit, paper,—rather than a less thickness at equal cost of the more expensive material; and this, although the thin rubber wall will give a higher insulation, as tested in the usual way, than will the paper.

And in designing a cable system a thorough study should be made of the details of junctions and terminals. There are plenty of good cables to be had, and there are enough good jointers to make the splices in the cables, but there is a sad lack of details, such as switches, lamp connections, and service boxes, fit to stand the ordinary accidents of use at high electro-motive force.

In closing, it is necessary to say a few words about the systems of cables or conductors which do not permit of the withdrawing of the conductors, including in this the well-known solid systems, so-called, of Edison and of Ferranti. The best known of these systems in the United States is the Edison tube, wherein three solid copper rods are wrapped with cord so as to preserve their distance from one another, and placed in an iron pipe of sufficient size, the ends of the pipe being closed with hard rubber plugs and the interstices being filled up solid with an asphalt compound. The tubes are usually 20 feet long. The joints between these tubes are made by slightly flexible links, and the links and the ends of the tubes are protected by a turtle-shaped casting, which is finally filled with compound similar to that used in the tubes. There is more electric energy distributed over this style of conductor than over any other in use in the United States. The Edison tube system is to-day essentially the same as when it was introduced fourteen years ago, and in our own city several miles of tubing laid in 1886 are in use at the present moment, and have been continually in use since first laid. The special virtues of this method of arranging underground conductors are that its method of joining conductors permits the making of service connections at the junction of any two tubes, and that the tubes form a sufficient mechanical protection to the conductors against any of the usual disturbers of the subsoil. The only instances in this city in which these conductors have been injured by street excavations have been those where the work has produced a general settlement of the soil or a partial landslide, causing the joints (which are not designed to resist longitudinal strains) to open out. An example of this occurred in the alley south of the Hammond Building, when the excavation for the Union Trust Build-

ing was made. The soil of the alley, including part of the foundation of the Hammond Building, started forward into the excavation and the Edison tubes were torn apart.

The celebrated Ferranti tubes have been described so often and have been so limited in their use that they require no description from me. You will remember that they contain concentric conductors designed to carry current at a pressure of 10,000 volts; that the insulation is paper soaked with ozokerite, and that the joints are accurately turned tapers, male and female. The system was lacking in flexibility, and required an unusual order of skill and specially accurate machinery in making up the sections.

Some eight years ago another solid system of conductors was tried in several cities and under different names. The conductors were stranded copper cables without insulation, laid in a matrix of asphalt, the asphalt being confined by a wooden trough and covered with plank. The plan failed because of the softening of the asphalt, allowing the conductors to sag together, or in other instances, where the asphalt was sufficiently firm to resist sagging, through the opening of cracks allowing water from the soil to reach the conductors and cause short circuits. I may say that the finding of an asphalt insulating compound which will remain viscous at minimum temperature of the subsoil of the Northern American states and will still be firm enough at maximum temperature to prevent sagging of imbedded conductors is still an unsolved problem.

Finally, there have been laid underground a great many cables simply buried in the soil. This is a favorite practice in Europe, and the European cable manufacturers make cables armored with iron strip or with interlocking wire specially for this work. In this country such special cables are not regularly on the market, and the practice is not in favor, because of the continual tearing up of our streets for different purposes without proper supervision of the excavators. Lead-covered cables are laid occasionally in streets not likely to be disturbed, a bed of concrete or a creosoted plank being laid on top of the cable to give notice to the careless excavator. I am sorry to say that my own experience shows that neither concrete nor plank is effective. Our local wielders of the pick are not expected to think, and, being directed to open a trench, will work on faithfully through either concrete or plank, varying their straightforward digging only by an occasional "undercut" to the obstruction. At least two Polish citizens of Detroit have been educated during the last three months as to the inadvisability of undercutting small sec-

tions of concrete uncovered in trenches. One of the two knows now that he struck an electric light cable, and that the destruction of the point of his pick and the accompanying blaze were due to physical causes. The other man disappeared for the day, after his early morning experience of this kind, and at last accounts was still firmly convinced that there exists on Washington avenue, in front of St. Aloysius Church, a short and direct passage to the nether regions.

THE CONSTRUCTION OF THE HEMET DAM.

By James D. Schuyler, Member of the Technical Society of the Pacific Coast.

[Read before the Society, June 4, 1897.*]

California has, within her borders, a number of high masonry dams, possibly more than any other state in the Union, certainly more than any other Western state, and nearly all of these dams have been built within the past 10 years. The most prominent of these, named in the order of their height, are the San Mateo, Hemet, La Grange, Sweetwater, Folsom, and Bear Valley, all of which have been repeatedly described and discussed in engineering societies and in technical journals, as well as in the local periodicals, with the single exception of the Hemet Dam, which, though second in height, is apparently but little known, and is seldom mentioned in print except by the journals in the immediate locality, none of which have, however, given it complete or adequate illustration. This is due partly to the remoteness of the situation of the dam and the difficulty of reaching it, as well as to the modesty of the men who have constructed it and put it in service, without the flourish of trumpets which ordinarily announces the completion of a work of such magnitude, and which might be regarded as entirely justifiable in the present instance, where such a substantial addition to the wealth of a community has been made and so notable an object lesson given of the possibilities of water storage in the arid region.

The writer, having planned the structure and supervised its erection by occasional visits as consulting engineer, has been frequently invited to write an account of its construction for the enlightenment of the profession as to its details, and has recognized that it is a duty, which every engineer owes to his fellows, to make such a public record of the works constructed under his charge as will serve as a convenient reference for the future. Until recently, the immediate spur or incentive required for the preparation of such data was lacking, and the good intention was repeatedly put aside by more urgent demands upon the writer's time, but, having been employed to write a general paper on "Water Storage and Dam Construction in the Arid Region" for the Eighteenth Annual Report of the Hydrographic Division of the United States Geological Survey, shortly to be published, he revisited the dam, revised

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his notes and drawings, and prepared an account of the work, from which the following is largely extracted by permission of the Chief Hydrographer, although rearranged and presented in somewhat different form.

Hemet Valley, Fig. 1, whose outlet is closed by the dam of the same name, is an elevated mountain valley on the southern flank of San Jacinto Mountain, in Riverside County. The general altitude of the valley is about 4300 feet above sea-level. It is in the region of pine timber, which rather sparsely covers the valley and the mountain sides. It is a cold, frosty valley, unfit for agriculture and suitable only for grazing, for which it affords a coarse, hardy wire grass that cattle appear to thrive upon. It has never been occupied, except by a single family; subsisting on the stock-raising industry, which has not been interrupted by the construction of the dam, as by far the larger part of the valley is still above the high-water line of the reservoir.

Mt. San Jacinto and Grayback, which stand as sentinels, one on each side of the great gateway of San Gorgonio Pass, are two of the highest peaks in Southern California, and the former, 10,987 feet in altitude, is a trifle the higher of the two. The principal drainage of the peak is into the San Jacinto River, of which the South Fork, flowing through Hemet Valley, is the largest tributary. The area of watershed above the dam is variously estimated at from 65 to 150 square miles, although no surveys have been made to determine its boundaries with precision.

No reliable records have been kept of the precipitation, either at the dam or at any other points on the watershed, but it is quite evident from the topography that the precipitation at the dam would be the minimum of the entire shed.

The outlet from Hemet Valley is a narrow canyon in granite, through which the stream plunges for nine miles, making a total descent of about 2000 feet to its junction with Strawberry Fork, where is located the pick-up weir, which diverts water from the stream into a flume conveying it to the distributing system in the valley below. Hemet Dam is located at the head of this gorge at its narrowest point.

When the enterprise of constructing the dam was first considered, in 1886, plans were drawn for a structure which, had it been built, would have been more startling in dimensions than even the notorious Bear Valley Dam, as a uniform thickness of 4 feet from bottom to top was proposed, and the dam was to depend wholly upon the arch for its stability. It was to be curved up stream, with the shortest possible radius, and to be of cut stone

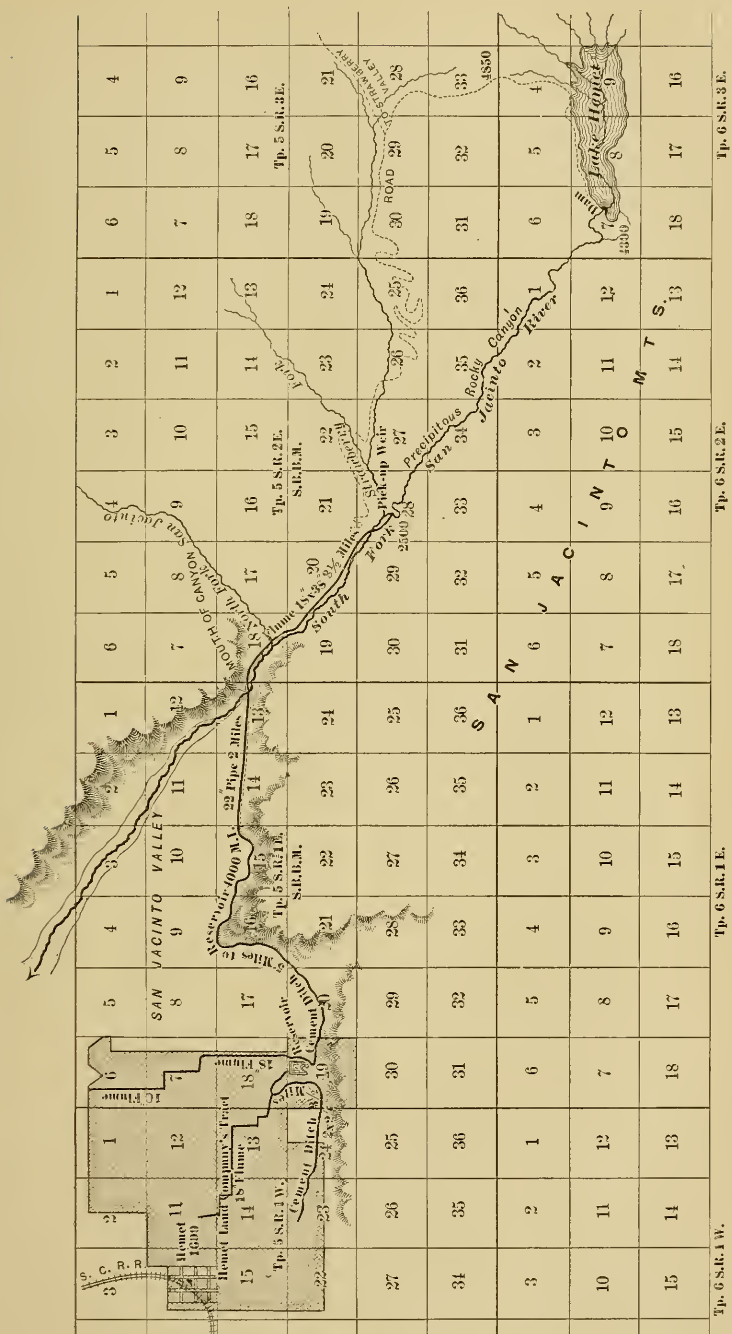

Lake Hemet
San Jacinto River
Precipitous Rocky Canyon
Pick-up Weir
Strawberry
STRAWBERRY VALLEY ROAD
North Fork San Jacinto
South Fork
MOUTH OF CANYON
SAN JACINTO VALLEY
SAN JACINTO MTS.
22" Pipe 2 Miles
5 Miles to Reservoir 4000 M.I.
Cement Ditch
Reservoir
Hemet 1600
Hemet Land Company's Tract
S. C. R. R.
4850
2500
Tp. 5 S.R.3E.
Tp. 5 S.R.2E. S.B.B.M.
Tp. 5 S.R.1E. S.B.B.M.
Tp. 5 S.R.1W.
Tp. 6 S.R.3E.
Tp. 6 S.R.2E.
Tp. 6 S.R.1E.
Tp. 6 S.R.1W.

FIG. I.

laid in cement. This structure was, however, not approved by the company, which shortly after changed hands, and, preliminary to the storage of water, it was decided by the new corporation, entitled the Lake Hemet Water Company, to first utilize the waters of the living stream to their full extent. For this purpose a 13-inch pipe was laid from the junction of the Strawberry and South Forks down the canyon $3\frac{1}{4}$ miles to its mouth, and thence out to the tract of 7000 acres of valley land acquired by the stockholders, over which the water was distributed in pipes.

The storage dam, though not actually begun, was in contemplation. Nevertheless, it was found that prospective land purchasers and home-seekers were skeptical of the sufficiency of the water supply with merely the normal stream flow of the South Fork as the only visible source, and, though the lands were otherwise all that could be desired, they were practically unsalable until the company began the actual building of the dam, and had finished it so far as to be able to store a considerable body of water behind it.

The site seemed specially suitable for a masonry structure because of the excellence of the bedrock foundation, the abundance of good granite and sand right at hand, and the narrowness of the canyon where it was to be located. A rock-fill dam was first considered among the possibilities; but, as the side walls of the canyon were no higher than the maximum height of dam proposed, most of the rock would have had to be hoisted and transported from quarries above and below, and the volume of material to be handled would have been so much greater than for a masonry dam that there was no apparent economy in favor of a rock-fill.

From the outset the projectors were determined to erect the best dam that men and money could build, and the writer was instructed to prepare plans suitable for the maximum height to which a dam could be built to advantage at this site. Considerable delay was occasioned by the necessity for constructing a wagon road up the mountain from the mouth of Strawberry Fork, and it required some time to induce the county supervisors to locate and build the road as a public highway. The company was anxious to have the road built directly into Hemet Valley by a route free from snowdrifts and on a maximum grade of 10 per cent., but other interests were strong enough to locate it on the slopes of a canyon intermediate between South Fork and Strawberry, where 18 per cent. grades were used, with many sharp turns, on a north slope where snow sometimes lies late in spring. This location is more convenient for the saw mills on Strawberry and North Fork,

but it compelled the construction of a branch road 5 miles long into Hemet, over a summit 500 feet higher than the reservoir. This road was finished in 1889, and in the summer of 1890 the plant for erection of the dam was assembled and excavation begun. The stripping of the foundations occupied several months, with the aid of a cableway for conveying and dumping the waste below the dam-site, and a considerable part of this time was required to excavate a deep "pot-hole" developed directly under the base of the dam, and within the exterior limits of the foundation. This hole was filled with bowlders and gravel tightly rammed in place, and might have been built over with perfect safety, but, as its depth was unknown at the outset, it was thoroughly cleaned out, although it required 500 yards of masonry to refill it.

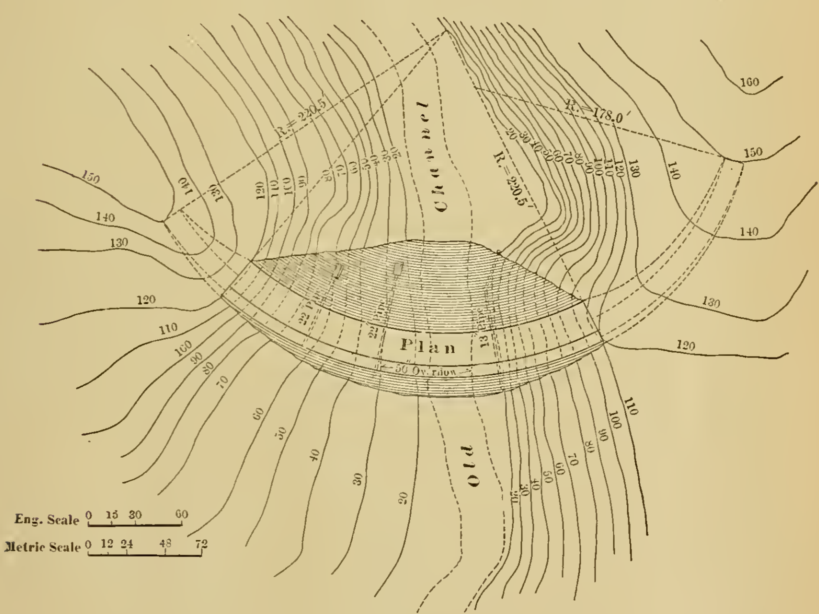


FIG. 2.

As a key or anchorage to receive the masonry of the dam, a center trench of irregular depth and width was cut in the rock on each side from bottom to top. While the work was progressing, the company's teams were busily engaged hauling up cement. The distance by the road from Hemet Station, on the Southern California Branch Railway, is 23 miles, and the total ascent to the summit is 2300 feet. The teams leaving the station every morning would go half-way up the mountain and be met there by teams leaving the dam at the same time, each team returning at

night to its starting point. The wagons were usually loaded with cordwood or lumber on the return trip. Owning their own teams and raising their own hay or grain, the company in this way reduced the cost of transportation of the cement to something less than $1 per barrel.

The erection of a sawmill to cut lumber for the boarding houses, stables, cement houses, shops, flumes, staging, and various other structures was the first essential in the erection of the plant, and the logs for this purpose were supplied by the necessary clearing of the reservoir basin. About 1,500,000 feet B. M. of lumber was cut in all, of which about two-thirds was consumed about the dam. This lumber cost $6 to $7 per 1000 feet. The tree-tops were cut up into cordwood.

PROFILE OF MASONRY DAM
(Looking Down Stream)

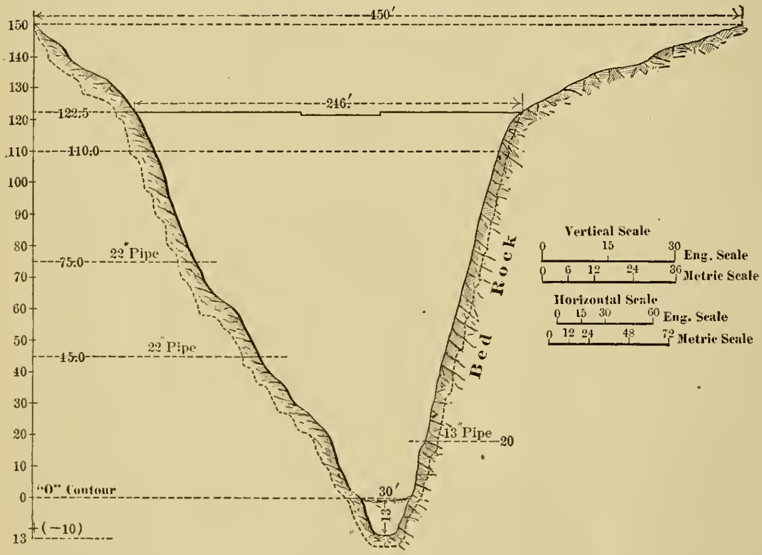
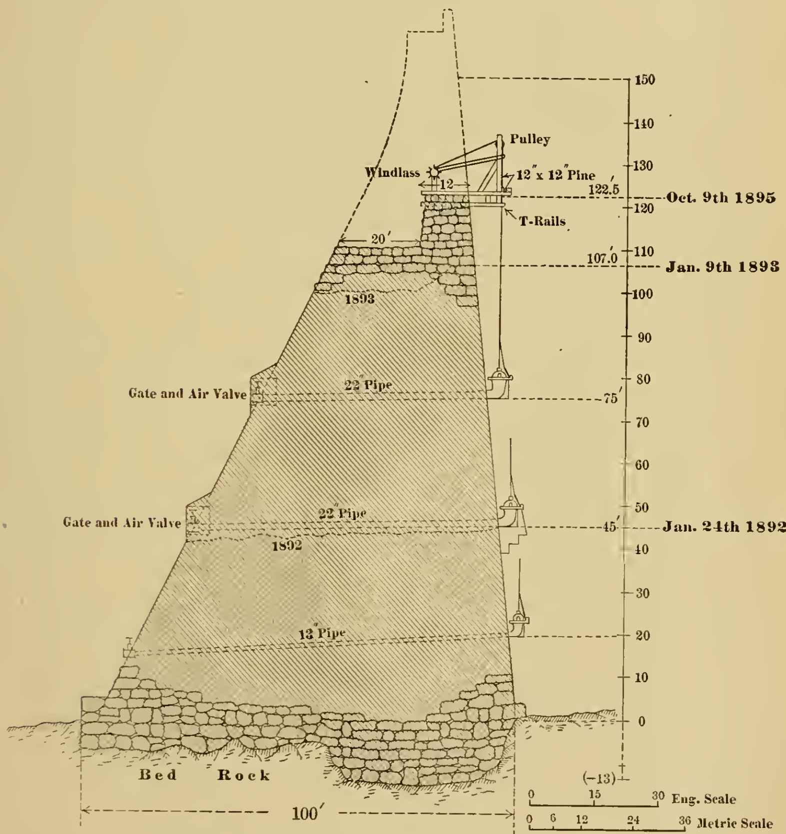


FIG. 3.

The actual erection of the dam began January 6, 1891, when the first stone was laid, and the work proceeded thenceforward without interruption until January 24, 1892, when severe weather and floods compelled a suspension of construction at the 45-foot contour, and four months elapsed before it could be resumed, when it was continued again without cessation until January 9, 1893, when the workmen were again driven off by a storm that filled the reservoir so rapidly that many of the buildings and tools were submerged, and the water ran over the top of the dam in a sheet several feet deep for a short time. By this time the dam had

reached the 107-foot level, at which the work remained until the fall of 1895, when construction was resumed and carried on to the present height of $122\frac{1}{2}$ feet above the creek bed, or $135\frac{1}{2}$ feet above the lowest foundations; and, on the 9th of October (the top of the wall having been finished off level, with the exception of 50 feet in the center, which was left one foot lower than the remainder as an overflow channel), the machinery was all removed and the work was considered practically finished, for some years to come at least, although it has been projected to go to the ultimate height of 160 feet above the stream bed.



SECTION OF MASONRY DAM

FIG. 4.

The dam, Figs. 2, 3, and 4, is 100 feet thick at base, and has a batter of 1 in 10 on the water face, and 5 in 10 on the lower side. Its present crest is 260 feet long, while the length at bottom is but 40 feet. It was carried up with full profile to the height of 110 feet above base, at which height it is 30 feet in thickness.

Here an offset of 18 feet was made, and the wall reduced to 12 feet thickness. At the top it is finished to a thickness of 10 feet.

The top of the dam is now level with the lowest notch of a gap in the ridge to the south, which has been filled with a short embankment of earth 6 feet in height. Any increase in height of the dam will necessitate the construction of an earthen barrier of sufficient height to close this gap. At the 150-foot level the waste water could be spilled over a broad, bed-rock sill between the dam and the gap referred to.

The dam is arched up stream with a radius of 225.4 feet at the upper face on 150 feet contour, and is built of uncoursed, rough granite rubble, laid in Portland cement concrete throughout the body of the work, the faces for 3 or 4 feet in thickness being laid in cement mortar, with large stones specially selected for true faces and beds. None of the stones were cut, although the facing stones were roughly scabbled. Before leaving the quarry all the stones were washed clean with jets of water from rubber hose under considerable pressure. This washing was usually done after the stones were chained and before they were hoisted above reach.

The total cubic contents of the dam are 31,105 cubic yards, requiring approximately 20,000 barrels of cement, which cost about $5 per barrel delivered on the ground.

The stone was all quarried within 400 feet of the dam, on both sides of the canyon both above and below, and was hoisted and conveyed to the wall by two cableways, each cable being about 800 feet long and 1½ inches in diameter. These were placed up and down the stream, crossing the dam nearly at right angles with the long chord of the arch, but diverging from each other and anchored to convenient trees on each side of the gorge below. At the upper end both cables were attached to points on the right bank. Their position was seldom changed, except to lift them higher up into the tree-tops and to erect "A" frames on top of the masonry to support them when the wall had reached such a height as to require it. Loads of 10 tons could be hoisted and handled with ease, and such a load could be hoisted 150 feet vertically and conveyed 200 to 300 feet horizontally in from 40 to 60 seconds. Two derricks, one at each end, were placed on top of the dam in such position as to receive the loads directly from the cable and swing them into position at any part of the wall desired. These derricks were operated with water power obtained from a 3-foot Pelton wheel, propelled under a head of 75 feet by about 80 miners' inches of water brought from the stream in a flume 1½

miles long. This flume passed under the concrete mixer, where the penstock was located, whence a 13-inch pipe carried the water to the wheel placed below the dam. This pipe was afterward imbedded in the masonry of the dam at about the 20-foot contour, and it is so arranged that it can be used as the lowest outlet from the reservoir.

The carriages traveling on the cable, and the devices for sustaining the hoisting fall as the load moved back and forth, were designed by the author and a very ingenious and capable superintendent of the work, Mr. E. L. Mayberry, himself a large stockholder in the company and a contractor and builder of varied and extensive experience.

The sand used was clean and sharp, and was accumulated constantly, as it was rolled along the bottom of the flowing stream, by a temporary log-dam reservoir, whence it was periodically discharged into a sandbox below by opening sluice gates. From the sandbox it was conveyed to the mixing platform by an endless wire rope carried with triangular buckets of sheet-iron, holding about a quart each, and placed at intervals of 20 feet along the double wire rope, which passed over drums in the sandbox below and on the platform above. The wire ropes were about 12 inches apart. The hoist was about 125 feet, and the horizontal distance over which it was conveyed was 350 to 400 feet. This device was operated by the same engine which propelled the rock crusher and concrete mixer. It was almost automatic in its operation and gave very little trouble, delivering the sand thoroughly washed in the quantity desired, and emptying it into bins, where the exact charge for a mixing was accurately gauged.

The concrete used to embed the blocks of stone was mixed in the proportion of one of cement, three of sand, and six of broken stone, crushed to pass through a 2½-inch ring.

The stones were placed not less than 6 inches apart, and the spaces between them filled with smaller stone, all well rammed into place with iron rammers. A bedding of concrete, 3 inches or more in thickness, was made for each of the large stones, and this was carefully rammed under the edges all around before other stones were placed against it. This use of cement enabled unskilled laborers to perform much of the work, and stone masons were employed only on the facings. The latter were paid $3 to $3.50 per day. Laborers received $1.75 per day.

The mixing of both mortar and concrete was done by machinery, which is undoubtedly superior to hand mixing in the quality of the output. The grinding and pounding of the particles

of aggregates together in the revolving mixing machine appears to result in the more complete coating of the sand and rock with cement than is possible to secure by hand mixing, however carefully the latter may be performed. That this intimate mechanical action is of positive value in increasing the strength of cement or concrete is apparently demonstrated by the remarkable tests obtained from the new "silica cement," now being introduced throughout Europe and the Eastern states, which consists merely of sand and cement ground together.

The mixing platform was located on the right bank, about 300 feet above the dam, which was as near as it was possible to find the necessary room at the most convenient level, which was at the 80-foot contour. From this point a trestle was built along the face of the cliff to the dam, and on this a double track was placed, over which iron cars, pushed by hand, conveyed the concrete and mortar to the line of the dam. The cars were dumped into chutes which conveyed the material to the level of the work, whence it was shoveled again into wheelbarrows and delivered where required. When the dam had reached the level of the top of the trestle, an elevator was built at the mixer and another track was carried out on top of the cliff, at about the level at which the work was completed.

Information as to the cost of the masonry or of any other portion of the work is withheld by the company, for reasons affecting its dealings with the County Assessor on the one hand and with the Board of Supervisors, having power to fix water rates, on the other. Under favorable conditions, some of the masonry was put in for as low as $4 per cubic yard.

The outlets of the dam, Fig. 5, consist of two 22-inch lap-welded iron pipes, 11-32 inch thick, placed at the 45 and 75-foot levels, respectively, in lengths of 20 feet, fastened together with flanged and bolted joints. At the up-stream ends of the pipes are cast-iron elbows turning upward and flaring outward to 30 inches diameter, and closed by hemispherical valves or covers, each manipulated by a wire rope passing over a pulley and windlass on a frame secured to iron "T" rails embedded in the masonry at the top of the dam. These covers are ordinarily removed, and replaced by cylindrical fish-screens, 3 feet diameter, 12 feet high, standing vertically on the valve seat of the pipe from which water is being drawn. The main control is had by gate valves set at the lower line of the dam, from which the water falls freely to the rocks below in a fine spray, collecting in a pool a short distance

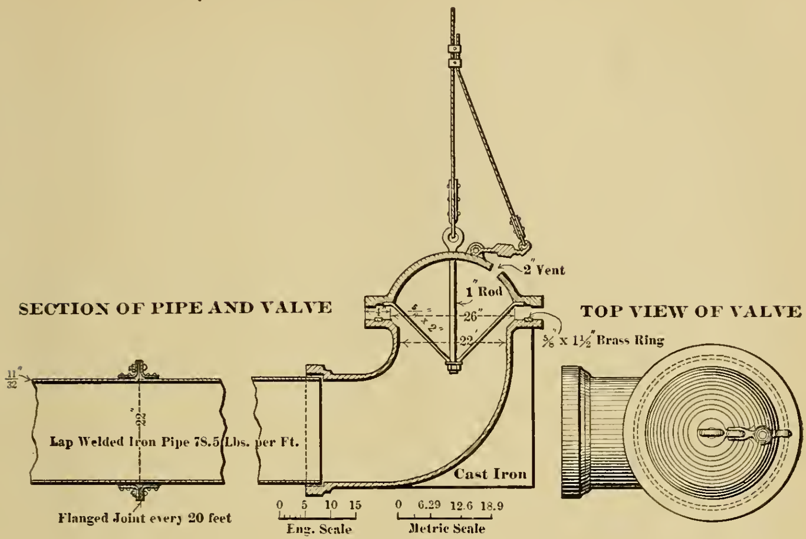

SECTION OF PIPE AND VALVE
TOP VIEW OF VALVE
2" Vent
1" Rod
26"
22"
⅝" x 1½" Brass Ring
Lap Welded Iron Pipe 78.5 Lbs. per Ft.
Cast Iron
Flanged Joint every 20 feet
0 5 10 15
Eng. Scale
0 6.29 12.6 18.9
Metric Scale

FIG. 5.

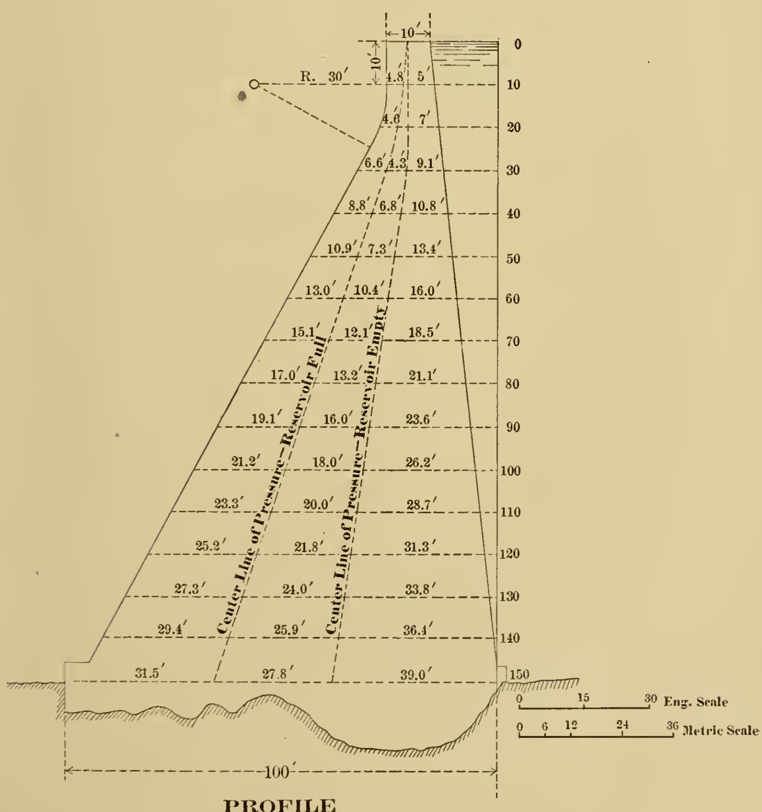

R. 30'
10'
Center Line of Pressure—Reservoir Full
Center Line of Pressure—Reservoir Empty
100'
0 15 30 Eng. Scale
0 6 12 24 36 Metric Scale
PROFILE

FIG. 6.

from the dam, and passing over a weir for measurement before beginning the plunge down the canyon.

Considerable leakage occurred through the masonry prior to the fall of 1894, when the water was drawn down and the entire face of the wall was carefully repointed. This resulted in materially lessening the leaks, so that they now are reduced to a mere sweating in patches here and there over the lower face, and the total leakage in the spring of 1897, with gauge at 101.5 feet, measured but 1200 cubic feet per day.

The profile of the dam, Fig. 6, is of the gravity type, in which the line of pressure, with full reservoir, falls just outside the inner third of the base at all points. The writer has always favored the arched form for all masonry dams as a measure of stability or as a factor of safety against all possible contingencies, even though their gravity be sufficient to render them entirely stable to resist maximum water pressure. In this connection it will be of interest to quote the arguments in favor of curved reservoir walls advanced by Professor Forchheimer, of Aix-la-Chapelle, Germany, in discussing a series of papers on "Impounding Reservoirs," recently read before the Institution of Civil Engineers.* Referring to a masonry dam eighty-two feet high, plastered and rendered over with two coats of asphalt, built by Professor Intze in Remscheid, Westphalia, he says:

A backwards-and-forwards movement, amounting to 1 1-16 inches, occurred during the filling and emptying of the reservoir, and the movement due to temperature was almost as great as this. The latter was due less to the temperature of the air than to direct solar radiation. The crest of this dam was 460 feet long, and was arched with a radius of 420 feet. One side was exposed to the sun longer than the other, and the more exposed part moved to and fro 7/8 inch in the course of the year, while the other part moved only 1/8 inch, the crest expanding 1-9000 of its length, or 5/8 inch. In arched dams such movements do no harm; but in straight dams these phenomena are objectionable. As dams are usually built during the warmer seasons of the year, the masonry has a tendency to contract in the colder weather. In a curved dam this can take place by movement of the structure without cracking, but not in a straight dam. * * * If the temperature was lowered 10° Cent. (18° Fahr.), and it was not free to contract, lesion amounting to between 140 and 280 pounds per square inch was set up, which is greater than the mortar would stand. * * * That a straight or almost straight wall incurred considerable danger of fracture is shown by practical experience. The dams of Habra, Grands-Cheurfas, and Sig, in Algiers, had broken, and in that of Hamiz a tear had occurred during the first filling. The Habra dam broke in December and the Grands-Cheurfas and Sig dams gave way in the month of February. The Beetaloo dam in Australia had also developed a crack

*Proceedings Inst. C. E., vol. cxv, p. 156.

⅛ inch wide in the middle of winter without any apparent cause. The Mouche dam, Haute Marne, a structure 1346 feet long and about 100 feet high, exhibited clearly the dangers attending straight dams. In the winter of 1890–91, when the temperature varied between 10° and 20° Cent. (50° to 68° Fahr.), and the water surface was 10 feet 8 inches below the normal level, seven vertical cracks appeared in the dam, situated at uniform distances of about 160 feet apart. They were widest at the top, and died out about 37 feet below the normal water level. Their aggregate breadth was 2⅞ inches. The cracks gradually closed as the temperature rose, and by the end of February, 1891, four of them had completely vanished, whilst the others had perceptibly contracted.

For the information of the profession, the writer will add that there are no visible cracks whatever in the Hemet dam, nor, indeed, in any other curved masonry dam which he has ever visited.

THE RESERVOIR.

The capacity of the reservoir, as it is completed at present, is 10,500 acre-feet (3,430,000,000 gallons). By carrying the dam to the 150-foot contour this capacity could be increased to nearly two and a half times, while the 160-foot level would give a capacity of nearly 35,000 acre-feet. The following is a table of capacity at different levels:

Height above base of dam.	Surface area, acres.	Capacity of reservoir, acre-feet.	Remarks.
40	2	33	
45	2.3	73	Lowest outlet at 45 ft.
50	3	113	
60	29	332	
70	62	773	
80	103	1,603	
90	133	2,787	
100	187	4,391	
110	252	6,598	
120	328	9,512	
122.5	365	10,500	Top of dam.
130	486	13,590	
140	601	19,077	
150	738	25,836	

THE CONDUIT.

As before stated, water released from the dam flows down the bed of the South Fork canyon, Fig. 1, 9 miles to the pick-up weir just above the mouth of Strawberry Fork, where it is diverted into a flume. This weir is a low timber structure of no special importance. Great difficulty was experienced, before the building of the dam and for a year or so after, in disposing of the sand flow down the canyon, and an ingenious mechanical device was

arranged by Mr. Mayberry for automatically settling and hoisting out the sand from the settling tank by the power of the flowing water passing over an overshot wheel at a sandhouse a little way below the dam. This has all become obsolete now, however, as the stream has been comparatively free from sand since the building of the dam, which evidently came chiefly from Hemet valley. From this it may be argued that the reservoir is destined to become rapidly filled with sedimentary deposit. The progress of this filling is as yet, however, imperceptible, and, as the reservoir is capable of impounding the normal annual run-off, the ratio of sand flow to water is too small to make alarming inroads upon the reservoir capacity.

The main conduit, below the pick-up weir just mentioned, is 3.24 miles in length to the mouth of the canyon, where it connects with a 22-inch pipe 2 miles long, which, in turn, discharges into an open ditch 5 miles in length, lined with masonry and plastered with cement, which delivers water to a distributing reservoir at the highest corner of the irrigated tract. The flume in the canyon is 38 inches wide inside by 18 inches deep, and has an average grade of about 140 feet per mile. The longitudinal joints of the bottom boards are battened underneath and calked inside with oakum, and triangular strips are nailed in the corners. The interior of the flume is coated with asphalt and the outside with lime whitewash, which is an excellent preservative of wood and adds greatly to the appearance of such a structure. The lining lumber is 1½ inches in thickness. A portion of the flume is built of redwood and the remainder of mountain pine cut from the reservoir basin, which, though knotted and inclined to warp, has nevertheless made a remarkably tight and serviceable flume. One of the peculiarities of this structure is that after completion the lumber appeared to expand lengthwise when wet, so much as to amount to about one foot in the first mile, so that the posts of the low trestles supporting it were thrown off their feet, and it became necessary to put in "expansion joints."

The main ditch leading to the distributing reservoir is lined with granite cobbles from the river bed, of about 10 inches maximum diameter, laid in lime and cement mortar in equal parts, and plastered with Portland cement and sand. The ditch is 2.75 feet wide on bottom, 7 feet at top, 2.75 feet deep, and has a capacity of 60 second-feet. A portion of it was rendered over with asphalt which was unskillfully applied, and, though serviceable for some years, has been removed and replaced with cement plaster. Ditch linings of asphalt require to be homogeneous to be successful,

ERRATUM.

In Journal of Association of Engineering Societies, Vol. XIX, No. 3, September, 1897, Page 95, Line 5 from foot. For "one miner's inch" read "one-eighth of one miner's inch."

apparently, as it refuses to adhere to masonry where there is any moisture in the latter.

THE DISTRIBUTING SYSTEM

through the tract consists of smaller cemented ditches, flumes, and pipes, of which there are 30 miles altogether, covering the entire area. The slope of the land is about 40 feet per mile from east to west, which facilitates the distribution of water in conduits of small size.

THE DISTRIBUTING RESERVOIR.

The dam of the distributing reservoir is of earth, 300 feet long, 14 feet high, 8 feet wide on top. In construction, a trench 10 feet wide, 9 feet deep, was excavated under the center line, and in the middle of this trench a tight board fence was built, with boards placed horizontally, from near the bottom of the trench to the top of the dam, to prevent the burrowing of ground squirrels and gophers, a function which it effectually performs. The trench was refilled with puddled earth on each side of the fence, and the puddle was also brought up to the top of the embankment. The reservoir covers about 20 acres in area, and has a capacity of about 90 acre-feet; and from it is distributed the supply to the lateral ditches and flumes covering the tract irrigated. The domestic supply pipe to the town of Hemet is also arranged to discharge any surplus water into the reservoir, as well as to draw from the reservoir in case of necessity.

THE LANDS IRRIGATED.

The area actually irrigated from this system was 1092 acres in 1896, and it is increasing year by year. The planting is chiefly in deciduous fruits, and is divided into 72 tracts, of which the usual size is from 10 to 20 acres. The rates charged for water are $2 per acre per annum, with an additional charge for domestic supply of $1 per month for each service or tract during the non-irrigating season, which is stipulated in the water-right contracts to be from November 10 to April 10. In the town of Hemet there are 55 taps paying a uniform rate of $1.50 each per month.

The apportionment of water by the water-right contracts given with the deeds to the land is at the rate of "one miners inch of perpetual flow from April 15 to November 15 of each year for each acre, which is equivalent to 39,312 cubic feet or 0.9 acre-feet. The rate of $2 per acre would therefore be equal to a charge of 5 cents per 1000 cubic feet, or $\frac{2}{3}$ cent per 1000 gal-

lons. No attempt being now made to restrict the consumer to this precise quantity, it is as yet uncertain as to whether this quantity could be made to suffice for the thorough irrigation of the crops which will there be planted. The quantity used during 1896, as measured over the weir at the base of the dam, was 111,600,000 cubic feet, an average of 102,000 cubic feet per acre irrigated, or a mean of 2.34 feet (28 inches) in depth over the entire surface. The computation does not take into consideration the possible loss by leakage and evaporation in the conduits and the distributing reservoir, nor the possible loss or gain in the flow down the 9 miles of canyon below the dam. The measuring weir at the dam is also imperfect, and the velocity of approach, which was unknown and neglected in the computation, would rather tend to increase the total volume stated, or offset the losses mentioned. The figures given indicate in a general way, however, that unless the irrigators are wasting water extravagantly while free to use what they like, the apportionment to which they are legally entitled under their water-right contracts is inadequate. The reservoir, when filled annually, may be regarded as capable of irrigating, or furnishing water for irrigating, about one acre of land for every 2 acre-feet of reservoir capacity, and therefore, as the present capacity of the reservoir is 10,500 acre-feet, it will supply 5250 acres with abundant water.

The freshets of winter, and the run-off from melting snow in the spring, are counted on quite certainly to fill the reservoir before the irrigation season begins, and ordinarily the summer showers add material reinforcement to the supply.

The normal summer flow of the stream, which is ordinarily about 4 second-feet, is considered as more than adequate to offset the loss by evaporation on the surface of the lake for the entire year, and therefore, taking one year with another, the supply available may be considered sufficient for the entire tract of 7000 acres. Further experience, both with the catchment from the watershed and with the duty of water in irrigation, is necessary, however, before definite estimates of this sort can be made with safety.

The soil of the tract is a fine, mellow, sandy loam, of great depth and fertility, seemingly unchanged in character as far down as 100 feet; and when the water table of this region shall have been raised to within 10 or 15 feet of the surface, after years of continuous irrigation, the duty of water upon the land will doubtless be greatly increased.

DISCUSSION.

Mr. Grunsky.—This dam is somewhat similar to the dam constructed by two irrigation districts at La Grange, on the Tuolumne river. The latter has a total height, as I recollect, of 128 feet. It is rather remarkable in this, that the water flows over the top of the dam. It is really a large diverting weir. The water drops from high-water level about 100 feet to low-water level. The amount of masonry in this structure is 39,000 cubic yards, which is a little in excess of the amount in the Hemet dam.

These dams, of unusual dimensions and unusual character, are becoming more numerous from year to year in California, and this state is taking the lead to a large extent in the matter of the construction of peculiar types of dams, as is quite well known to all the members of the society.

There is one feature dwelt upon by Mr. Schuyler that indicates in what way a water supply system for irrigation can be made profitable. It is the combination ownership of land and water. When parties not interested in the sale and distribution of the water own the lands to be irrigated, the demand for water grows slowly. To illustrate how a combination ownership of land and water may be a financial success, an example from Kings river may be cited. About 1882 the promoters of an irrigation enterprise, known as the "76" canal, commenced operations by securing water rights, and at the same time purchasing about 40,000 acres of land scattered through the district commanded by the proposed canal. The price paid for the land ranged from $5 to $10 an acre.

They then expended about $200,000 in constructing their works. The main canal was made 100 feet wide on the bottom and about 8 feet deep. They sold the land at a price sufficiently high to cover the cost of canal construction and leave a handsome margin besides. Their operations were so successful that their properties, which had by 1886 cost them about $300,000 in the aggregate, were then estimated to be worth $800,000.

It is a fact too often overlooked that where irrigation ditches are constructed simply for the sale of water the people are very slow to take the water, and the revenue from its sale increases slowly. It is rare to find an irrigation work not combined with land sales, which has been profitable from the outset.

Mr. Wagoner.—I would like to have Mr. Grunsky explain more in detail the arrangement for taking the water out of the river, especially as to the head works.

Mr. Grunsky.—The Kings river is a peculiar stream. It

leaves the foothills over a very broad bed of coarse cobbles, some large enough to be called bowlders. On account of bars in the river at various stages there are subsiduary channels, and the water is very easily turned from one into the other. By a temporary barrier a larger flow of water may be diverted into one of these channels, from which a diversion is easily accomplished. In this particular case the southernmost channel of the river was selected. At its head the cobbles were thrown out until the channel was sufficiently enlarged to cause a large portion of Kings river to flow in it. Wherever an obstruction was met with that would deflect the water from the southernmost channel, the one leading the water off was closed, so as to hold the southernmost channel full of water. From this channel a cut about 9 feet deep is made into the south side bench land, and in this cut the head-gate is placed. It is 100 feet from bank to bank. The head-gate or regulator serves as a bridge, weighted on top, and is divided into 20 openings. The openings are between posts, and gates move vertically between these posts. In four of these gates there are revolving shutters, something like a butterfly valve. Its width up and down stream is 30 feet. The bridge is just wide enough for convenient travel.

Mr. Wagoner.—What kind of lumber was used?

Mr. Grunsky.—Redwood was used for the lower part of the structure, and some pine was used above. The simplest types of structures are used to divert the water from the canal. Very light weirs of timber are placed across the canal. Generally the weir is carried into the banks for a short distance and then bulkheads built, to which wings are connected. The space between these bulkheads is floored, sheeting being used on the upper and lower line of the floor, and is divided into about 4-foot spaces by means of inclined posts. These posts are provided with grooves, and inch boards slide in these grooves. The weir boards are moved by hand, and can be removed singly. Water flowing over the top of them drops upon the floor of the structure below. They are supported by inclined shoring from below. A plank is generally laid across the top of the weir posts in such a way as to give convenient access to any part of the structure. This serves as a footpath. The same type of structure answers for all lateral canals to reduce fall and to aid in diverting water.

Mr. Henny.—In connection with this enterprise, Mr. Grunsky has referred to the fact that the promoters first bought the land, which he considers to some extent the secret of financial success. It seems to me that there may have been still another

reason for the financial success of the Kern County enterprise, and that is in the fact that no large amount of money was necessary to build storage works; all that had to be done was simply to divert the water from the river. This was in 1882. Presumably at that time all the river water had not been appropriated. The question may be asked whether it has become necessary for the company in question, in case they did take water that had been appropriated, to settle with the people who had a prior right to it. Such settlement, of course, would involve additional expense. It appears to me that in prospective irrigating enterprises the element of time is often improperly left out of account. The cost of the works is figured, and the annual revenue expected from the territory covered; but usually promoters fail to allow for the number of years that must pass before all this territory is settled, a factor which I think has much to do with the financial failure of many such enterprises in this state.

Referring to the expansion of timber, I find that lengthwise swelling of the wood, as shown by the author, is not confined to redwood. On an average, redwood does not swell lengthwise much more than other woods. The amount of lengthwise shrinkage is very uneven, however, varying in the experiments that I have made from 0.07 to 0.39 per cent., and averaging 0.141 per cent.

I might state that in 1887 I was planning in Arizona a flume that was to be constructed of mountain pine, which I presume is identical with the pine of the San Jacinto mountains; and I was told by those who had experience in the longitudinal shrinking of that lumber that it was greater than in any other timber they had seen. We made some experiments by sinking a plank under water and leaving it for a month and then letting it dry out. I do not remember just what it was, but it was about two and a half times greater than the amount given in the tables for longitudinal shrinkage. That wood is generally softer than the California species and more liable to be knotty; in fact, it is difficult to get sound, first-class timber from it. We found that a block that was thoroughly waterlogged, having been submerged for a month, and then allowed to dry for 2 days, would take fire from a match and would be entirely consumed.

Mr. Grunsky.—Mr. Henny suggests that in irrigation works there may be a good deal of expense in buying up water rights. I will state that nearly all the canals in the great central valley of the state are engaged in more or less litigation. It is very difficult indeed to determine just what the rights of a canal owner are.

The law prescribes that when a person desires to take a water right he may post a notice. The notice is generally written in a very indefinite way, and very often refers to the spot where the notice is posted, without designating where that spot is; and when a man wants to take 300 inches of water he writes 30,000 inches, so as to cover enough by the notice, and that notice is then filed in the office of the County Recorder. When he gets ready to construct his ditch, although he may have described in his notice a canal 30 feet wide, he is not ready to build any such a canal, and builds a ditch only 2 or 3 feet wide on the bottom. He uses that for perhaps 10 years before he is ready to enlarge. There is no record made of such facts. They live only in the memory of the people in the neighborhood, unless the ditch owner gets into litigation and the matter is brought up in court. This condition of things in our state has brought on almost interminable litigation as to water rights, entirely aside from those caused by the riparian doctrine, according to which the owner of the land upon the banks of a stream is supposed to have a right to have the water flow past his land undiminished in quantity and unimpaired in purity. The law needs to be revised in regard to the acquisition of water rights. There should be one central place where all records are made. No one should have a claim to water until he actually takes it and puts it to beneficial use. The notice should fix the time, if he complies with additional requirements, to which the taking of water is to be referred, and his ditch capacity and the amount of water taken should be determined by competent state authority by actual measurement of the ditch he constructs. There should be a state department in which all records relating to water appropriation are kept, and a system of ditch measurements should be instituted so that records would be concentrated at one point, and not scattered through all the counties. Individual ditch owners and all municipal and other corporations that are interested in water would then know just exactly what their rights are. If a good permanent department of this character could be instituted it would certainly be of great advantage to the state.

PROFESSOR SOULE.—The old method of the Spaniards and Mexicans has come in contact with the method of riparian ownership brought over from England, and there is a rivalry of those two systems in our state, the state having been originally settled by the Spaniards and subsequently by the English. I have had occasion to look into these matters, and have exchanged views on it, and I do not think that we exactly know where we are on this question. I quite agree with Mr. Grunsky's suggestions for improvement.

Mr. Henny.—Mr. Grunsky's plea for a central place of record cannot be too strongly endorsed, but I think he has only partly stated the legal troubles. He has not mentioned the question of underground water. In the southern part of the state there are many companies dependent upon that source for supply. The law provides that percolating water belongs to the owner of the soil, and he can do with it as he pleases, and anybody who is damaged because of its use has no redress. On the other hand, the law speaks of "underground well defined streams," which are subject to riparian ownership and appropriation, the same as surface streams. These terms are not specific enough. It is sometimes hard to tell when a stream is well defined. The State Engineer's office could be of considerable service in the way of giving advice on questions of this kind, and such advice would have due weight in the courts and would establish presumptive evidence.

THE NEW ROAD LAW OF MONTANA.

By M. S. Parker, Member of the Montana Society of Engineers.

[Read before the Society, March 30, 1897.*]

The law recently enacted† making county surveyors general superintendents of all roads in their respective counties is a step in the direction of progress, and I sincerely trust that the surveyors throughout the state will make an effort to prove the wisdom of this progressive measure. They will be annoyed by the existence of that relic of antiquity, the present road-tax law. Rome, however, was not built in a day, and the perfection of road laws is not to be accomplished in a single legislative session. We must take the laws as we find them, and make the best use of the opportunities afforded thereby.

One of the worst features of road laws is that they permit tax-payers to pay their road-tax in labor instead of in money. This law was inherited by the United States from England, where it was introduced in the eleventh century,—a relic of the feudal system brought over from the continent of Europe. For a long time this system was continued in England, and during all the time it was in force the roads were in very much the same condition as they are now in the United States. A good many years ago the law was abolished, and, as a consequence, few countries can to-day boast of better roads than England. The United States is lagging along behind the mother country, though we claim to have progressed more rapidly than England by reason of our freedom from old-established customs that retard progress there.

This custom of working out road-taxes, which has long been abandoned in England, is adhered to tenaciously in most parts of the United States, and, as a consequence, our roads are as much behind the times as is the old custom referred to. Farmers are frequently censured for bad work done upon our highways by them. The fault is not theirs, but of the system under which they work, and that system would produce practically the same results under any other class of men. The road supervisor warns out the men, and, in a general way, tells them what tools to bring. The

*Manuscript received September 8, 1897.—Secretary, Ass'n of Eng. Socs.

†Road and County Surveyors' Laws of Montana are published in full in the Journal of the present year. See Proceedings of Montana Society of Engineers, page 9 of the present number, and vol. xviii, No. 3, March, 1897, page 44.

men come or not, as suits their convenience. The supervisor, however experienced he may be in road building, cannot accomplish much with an inexperienced and very uncertain crew to work with. The main object of the worker, in most cases, is to get in the day and satisfy the tax. The road overseer or a contractor, with a well-organized and thoroughly equipped crew under him, is able to accomplish work better and infinitely cheaper than the disorganized crews called out at times to work out road-taxes. Work can be laid out for such organized crews by the engineer of roads, and it can be done as it should be, from the beginning. Under this system, in course of years, the country would be netted with good roads instead of the poor roads to be found all over the United States as a result of the old feudal law that has remained on the statute books of most of our states since the beginning of our country.

The road-tax in Montana is $3 per capita per year for each able-bodied man over 21 and under 45 years of age, or one day's labor on the public roads in lieu of such payment. The right to pay said tax either in labor or in money is optional with the taxpayer. Of those who elect to work out the tax, and so inform the county assessor, probably not one-half ever report for a day's work on the roads. If the road-tax were reduced one-half and made payable in cash only, the result on the roads would soon be realized and appreciated by the taxpayers at large. First-class roads have never been built anywhere under the old law, and there is no reason to expect that they will be in the future.

The Legislature of Montana has recently passed a law placing the roads under the supervision of county surveyors. This is a step toward securing good roads; but the Legislature has handicapped the work by a road-tax law that permits the working out of road-taxes. Had the labor-option clause been omitted, and had the tax been made $2 instead of $3 per capita, the law would be in accord with wisdom and common-sense, the outgrowth of universal experience. The greatest obstacle in the way of good public road building is this law permitting the working out of road-taxes.

WORKING ROAD-TAX HANDS.

This, in my opinion, is the first and only problem. The plan that will be adopted in Cascade county for working out road-tax is to appoint a manager in each township where necessary, whose duties will be to supervise the work of those who elect to work out their road-tax. General instructions will be issued to these managers as to how roads should be built, and they will conform,

as nearly as possible, to these instructions. It will be the duty of these managers to see that every man in his district who elects to work out his tax does so. As the manager cannot work with less than five men, except under certain provisions, he will, if desirous of working, see that his crew of five is complete. No money will be spent under the direction of such a manager without being ordered by the county surveyor. The main object is to get done the work that is due, relying on the manager to put it where it will do the most good. Farmers working near their homes will do something for their own roads. They cannot be taken far from home to work. A man and team will be taken as equivalent to two days' work, as by the law required. Managers must depend upon this means to obtain teams for their work. These methods will be used to keep roads passable throughout the county. All such managers will give bond to the county surveyor in the sum of $500 for faithful performance of his duty and as custodian of property.

DISTRICTS.

The county will be divided into four districts, to simplify accounts, and each district will have a manager, under whose direction all permanent road building will be done. Each of these managers will have an organized force under him, and will work under the personal direction of the county surveyor. These outfits will be moved from place to place, living in camps.

CASCADE COUNTY POLICY.

It will be the policy of the county surveyor to keep the organized crews on the main roads leading through the county,—the main arteries of travel,—and to systematically build permanent roads, as far as the means at hand will permit, macadamizing where necessary. If this system is carried out for a few years, there will be good main roads throughout the county. Lateral roads will be left to the last, and work done upon them only to the extent of keeping them passable.

GRADES.

As for grades, this is largely a matter of topography. Grades should be kept down to the limit of the territory traversed. They should be the best that the ground affords. Grades should never be sacrificed to property rights. If a road is worth building, it should be located where it belongs. The keeping of a record of grades, as required by law, is practicable, but it will take time to

accomplish it, as nothing has ever been done in the matter of grades heretofore. It will be the policy in Cascade county to begin a system of grades from Great Falls, the county seat, using a Government bench mark as the datum for all levels. Levels will be run as soon as practicable on the main roads leading through the county, and bench marks established at intervals of a mile. Permanent roads will be built to established grades. I do not apprehend any present necessity of carrying the matter further than the maintenance of proper grades on roads to be built in the future, and in changing old roads, where practicable, to reasonable grades.

Cascade county has about 1000 miles of road, and to establish grades for all this mileage would be folly at present. It will require years to get many of the little-traveled lateral roads up to an established grade.

CULVERTS AND DRAINS.

These will depend upon circumstances. At present no standard is adopted.

GRADING MACHINES.

These machines are well adapted for road grading in certain localities, particularly in a prairie country. In some parts of Montana they can be used to advantage, in connection with a road-roller, to pack the newly graded road. The road-scraper is a useful machine, particularly in leveling earth roads that have been badly cut up and left rough after the spring rains.

A road-grading machine, together with a heavy road-roller, will be recommended for use in Cascade county in the near future.

I am firmly of the opinion that the change in road supervision will result in good to the state. The duties of the county surveyor will be arduous and will require good executive ability on his part. It remains with him to prove the wisdom of the change in management of county roads. The compensation is entirely inadequate for the ability required to properly administer the duties of the office. A competent engineer can hardly afford to devote the time necessary to conduct the affairs of the office. This will be a serious obstacle in the way of procuring the best talent. It is to be hoped, however, that the county surveyors of Montana will do all in their power, during the ensuing two years, to make the law, of which our state is the pioneer, so successful in its operation that two years hence it may be so improved as to become a model for our sister states to accept.

DISCUSSION.

Mr. Kirkendall.—If a man has neither money nor property, and if he is invited to work on the road and refuses to do so, is there any law to make him work or confine him in jail.

Mr. Penwell.—I believe there is.

Mr. Thorpe.—It appears to me that allowing the furnishing of a substitute is one of the objectionable features in the new law, and one of the matters we should endeavor to have repealed at the next meeting of the Legislature. I think every man should either do the work himself or pay the road-tax in money. At any rate, if the substitute is not fully able to do the work, I do not believe we are compelled to take him.

Mr. Keerl.—As there appears to be some doubt as to the operations of the new law, I move that the Attorney-General be called upon for a comprehensive opinion on this law.

Mr. Wardwell.—Mr. Parker speaks of establishing grades for roads. It appears to me that each county surveyor should decide for himself the proper grade to use, as the conditions are so frequently changed in this western country. A road, at first unimportant, may, in a short time, become very important, owing to the opening up of new mines or other improvements. A road over which loads of ore, weighing from four to six tons, are to be hauled will not admit of heavy grades.

Mr. Wade.—A chain will hold only what its weakest link will hold. We can draw over a road only what can be drawn over its worst place, and consequently that one place will rule the traffic that goes over the road. It appears to me we should pay particular attention to grades. The need of proper grades is particularly apparent to freighters. Recently a freighter, in urging me to change a grade on a certain hill, said: "Why, Mr. Wade, every time we load for Helena we really load for that hill." With a proper grade at that particular point, 25 per cent. could be added to every load that passes over that route.

THE CONSULTING ENGINEER IN MUNICIPAL AFFAIRS.

By Wm. H. Searles, Member of the Civil Engineers' Club of Cleveland.

[Read before the Club, September 14, 1897.*]

In the administration of the material affairs of a great and growing city no one will deny the importance and necessity of an engineering department. So many features of civic growth relate to the physical and material improvement of the territory occupied by the city, and these so evidently demand, for their proper management, the study and superintendence of men skilled in technical details that the employment of civil engineers becomes a matter of course.

In the village stage of city growth this feature of the public service may properly consist of a chief engineer and a small corps of assistants. The chief engages personally in all the engineering work done, whether in field work or office, with the assistance of a few young men. But, as the city increases in size and the amount of work grows in proportion, this simple method of administration becomes impossible. The duties of the engineer office are subdivided again and again; at first perhaps only into a field and an office corps; then the field corps is subdivided by districts of the city or by distinct classes of duty, or both; the office corps is similarly divided and draftsmen of different degrees of skill are assigned to the work suited to their several abilities; but all employes, whether in field or in office, are still under the immediate orders of the chief. Such a system grows up by the gradually increasing demands upon the department, and without any special design; and it works well enough for a series of years, but at length it becomes unwieldy by its very expansion. The chief finds himself overtaxed by the multiplicity of items brought to his notice, while the assistants are embarrassed and delayed for lack of prompt and definite orders.

To obviate the difficulties growing out of this state of affairs it is customary to reorganize the engineer department by the establishment of a number of bureaus, each devoted to a particular class of work exclusively, and each presided over by an engineer who makes that class of work his specialty. Such a head of a bureau directs largely the details of work under him, subject, however, to

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the orders of the chief engineer, to whom he reports from time to time, and upon whom the responsibility for the character of the work accomplished finally rests. This form of organization is excellent in design, and, if properly carried out, usually secures the execution of the details of routine work with satisfactory dispatch.

The organization is similar to that adopted by railroad companies and private corporations doing business on a large scale. It so subdivides the labor that no part is necessarily neglected, and, while requiring ability in some one line on the part of the head of each bureau, it does not require of him ability and experience outside of the duties of that bureau. These subordinate heads of bureaus may therefore be, and they generally are, young men of good parts, but possibly of an experience limited to the scope of the bureau over which each presides.

A large part of the duty of a city engineer is found to be routine in its nature, of which repairs form a prominent feature. The work to be laid out is governed by precedent and patterned after work previously performed. A pavement worn out is to be relaid to the same grade, or a sewer too small is to be replaced by a larger, or a bridge superannuated is to be rebuilt. The work having been authorized by Council, is ordered by the chief, and is executed under the direction of the bureau head and his assistants. This seems so simple in statement that one feels confidence in the smooth and satisfactory execution of the work demanded, and such is usually the case, as far as routine work is concerned. Nevertheless, the multiplication of items in the ever-widening territory of a great city, and the increasing demand for repairs added to the demand for extensions and additions, serves to burden each bureau, and most of all the chief engineer, with a weight of duty and responsibility unrealized by any except the incumbent himself. It is only by severe application to duty, and often by overwork beyond the stipulated office hours, that the business of the office is kept abreast of the city's demand.

This general description fits quite well the present condition of the engineer office of the city of Cleveland. The city has long outgrown its village conditions and even those of a minor town. It not only aspires to metropolitan proportions, but finds itself compelled to assume them by the increasing demands upon it of commerce, of manufactures, and of the thronging population which these great industries attract and support. Not only increasing numbers, but also increasing wealth, make it the plain duty of the city government to provide clean and comfortable thoroughfares, wholesome conditions as to sewerage, a pure and abundant supply

of water, safe, permanent, and commodious bridges and viaducts, and beautiful and health-giving parks and boulevards for the use and comfort of the citizens.

Not less is it the duty of the city government to afford all possible facilities to the commerce that already seeks this port, and to commerce that would come here if opportunity and space were afforded for it. Here is a herculean task, yet one upon the proper execution of which the future prosperity of the city largely depends. It involves the expenditure of millions of dollars, while the proper and wise investment of this money is largely an engineering question. These great improvements which coming generations will be called upon to pay for should be designed and executed with reference not only to our needs of to-day, but to the wants of the century to come. Works of a temporary and flimsy construction, such as were excusable in a young community fifty years ago, are not to be tolerated for a moment. The improvements must not only be well designed, but must be permanent in character, so as to avoid as far as possible, for the future, the expense of either alterations or repairs.

The necessity for these improvements is conceded; the legislation precedent to the raising of the funds has already been accomplished. The question most important in this connection now is, on whom is to devolve the responsibility of devising and maturing the engineering plans upon which the expenditures are to be made. Ought this burden to be laid on the present engineer office of the city as now constituted? Most clearly not. It would be a gross injustice to the officials themselves to pile upon them these added duties when they are already taxed to the limit of endurance by their current official duty. Nor could we hope for the best results in plans for new work to which only hasty and partial attention could be paid in the intervals snatched from other pressing engagements.

Neither would it be wise to intrust these vast material interests to the care of another subordinate bureau of the engineer office, to be called perhaps the Bureau of Design. It would not be wise, because a bureau is necessarily limited in scope and authority; its work is performed largely by assistant engineers, without a broad experience, and must come up for revision and correction to the chief engineer probably a number of times before final approval. Were it simply a matter of detail it might be left to such a bureau to perfect, but we have here a problem of the broadest nature, involving untold interests in the future, and one that is to be solved only by the close and devoted study of well-trained and experienced

engineers, of liberal ideas, and free from other and distracting duties.

The several great problems now before the city, of sewage disposal, of harbor improvement, and of park adornment, though separate in themselves, have the common feature that they deserve to be treated comprehensively, and so carried out that every part shall be consistent with the rest. No detail should be decided upon except as it will fit properly into its place in the general design for all time to come.

In order to secure the end in view and guarantee that the funds to be expended in a grand municipal improvement shall be rationally and economically expended, the city should call into being a co-ordinate branch of the engineer office charged with the sole duty of considering the general problem in all its aspects, commercial, financial, and technical; to be presided over by an engineer of national reputation, who should be required to give his whole attention to the questions in hand. This officer should be furnished with offices and assistants quite distinct, so as not to interfere in the least with the routine duties of the present organization. After properly gathering all necessary data, he should be allowed sufficient time properly to weigh all the facts and to evolve a design that will never need to be repented of. Upon the completion and adoption of these designs they should finally be turned over to the chief engineer for execution, with the advice and friendly co-operation of the designer, who may perhaps be designated by the title of consulting engineer.

By such a differentiation of duty great advantages to the city are to be secured. Let all new work originate in the office of the consulting engineer. The plans and specifications will then be prepared on a scientific basis, and in accordance with the best practice of the world. The consulting engineer in the privacy of his office, and free from the demands upon his time so constantly made by the public upon the chief engineer, can work out a comprehensive and consistent scheme of improvement sufficient to meet all reasonable demands. Drawing upon his own resources as an expert, and in friendly communication with the best engineering talent the world affords, he will produce results on which his own professional reputation will be staked, free from all political influences or petty personal favoritism in their design, and thus give to the city a body of improvements of which it may justly be proud for all time to come.

The consulting engineer should have the privilege of selecting his own assistants, in order that his ideas may be thoroughly car-

ried out and expressed by them. For all information on record he would call on the chief engineer. For any new surveys or examinations he may call on the chief engineer, who will order them made by regular assistants, or, if the examinations were special in their nature and likely to interfere too seriously with the regular work, a special corps might be temporarily organized for the purpose. The plans and specifications would be matured directly under the eye of the consulting engineer, and would exhibit a harmony of design and completeness of detail impossible to realize under less favorable circumstances.

On the other hand, the chief engineer, being relieved from the responsibility of originating new and important designs, can give his undivided attention to the work of construction. By a well organized corps of assistants he may so direct the laying out of the work and the inspection of materials, and so control the quality of workmanship that every part of the scheme shall be thoroughly and consistently executed to his own professional credit and to the enduring advantage of the city he serves.

This last and most important division of expert service,—that of consulting engineer,—is not in the least suggestive of antagonism or jealousy in the engineer office. The division is a natural one, and founded on scientific principles. It is in accord with the best engineering practice and with the functions of the human mind. The duties of the two co-ordinate branches are quite distinct, yet perfectly complimentary to each other. The duties of the two require for their perfect performance different orders of mind. A man well adapted to the one is presumably not so well adapted to the other. By the division of duty into two classes the city obtains superior service in each. It is not a division into theoretical and practical engineering, as some might ill-advisedly infer. The designing engineer must be as practical as the constructing engineer; but he must also be so familiar with the immutable laws of nature, the strength of materials, the results of many tests, the use of many intricate formulæ necessary in the proportioning of parts, and with all that vast mass of information which goes to constitute the equipment of an expert engineer; that one cannot reasonably be expected to excel in this line who is charged with directing a large force of men, and seeing that their several duties are properly performed from day to day on works already under construction.

This division of expert labor is not without precedent. It is common on the more important railroads and wherever the highest grade of engineering work is to be accomplished. There can be

no good reason why the city of Cleveland should not avail itself of the same method. The great public interests at stake demand it; by no other means are the best results to be secured. It is in line with the only true economy. The cost of the additional office is not worth considering in comparison. As well might a steamboat company dispense with a pilot to save his salary.

The present is a most opportune time for making the innovation here, on the eve of enterprises heretofore unparalleled in this city, and requiring expenditures of money beyond all previous estimates. Naturally, in undertaking a new voyage the first step is to provide a pilot.

It may be objected to this general proposition that the end to be gained may be reached by the employment of a temporary commission of experts, to be called in as the occasion may demand from to time.

To this objection it may be replied that,

First. The very fact that such commissions have been several times created by this city proves conclusively that the necessity for a consulting engineer in some shape was felt to exist at those times, and is likely to occur again.

Second. The men serving on those commissions have been called from distant cities with minds preoccupied with their home duties, with little or no prior familiarity with our local conditions, depending upon such facts and figures as may be furnished them on arrival, and upon such hasty personal inspection as a one day's drive over the ground will enable them to make.

In contrast with these conditions, consider the advantage to the city in the services of a consulting engineer permanently engaged, giving his whole interest and attention to the problems here to be met, familiar with the records of the city, and able to make further examinations and surveys at any time that such seem to be necessary.

Third. The report of a foreign commission carries no authority with it. It is true the members have been selected for their high reputation and well-known ability; their report is presumably formulated upon their combined judgment, with all the care that the time at their disposal will permit. It may be a monument of wisdom, and yet after it is received and filed no one appears to feel under any obligations to follow its direction.

On the other hand, if a similar report were issued from a municipal office under the authority of a high municipal officer, such as a consulting engineer should be, the report would carry weight, and those who were opposed to it would have to show

cause why it should not be adopted. Its author would be present to answer objections and to defend its measures if necessary.

Fourth. The expense connected with such commissions is necessarily great, yet their advice is confined quite strictly to the questions laid before them. A very few such commissions in the course of a year would cost an amount equal to a salary at which any member of the commission could be secured to serve the city in a permanent capacity, with the inestimable advantage of his constant personal presence and study of the engineering questions that will continually arise.

Fifth. The report of a commission has no necessary relation to those which have preceded it. They may therefore be inconsistent, if not contradictory, and it might be impossible for the city to follow them all literally.

On the contrary, the reports and designs issuing from the permanent office of the city's consulting engineer would exhibit a uniformity of purpose and plan, and would be consistent one with another, so that all could be reasonably carried out with the greatest advantage to the city.

As the city solicitor, or director of law, is frequently called upon for opinions as to the constitutionality or legality of certain measures proposed, so would the consulting engineer be called on to decide upon the practicability and economy of various schemes proposed; his adverse opinion,—based on a knowledge of nature's laws, which never can be violated with impunity,—serving to save the city many thousands of dollars which might otherwise be squandered in useless experiment.

Under a consulting engineer we should see much less of the now common practice of signing local remonstrances against proposed improvements, partly because such improvements would have been so wisely designed as to be open to very little criticism, and partly because, as part of a general scheme, no alteration in plans could be made without doing, at some other point, greater actual harm than that locally complained of.

It thus appears from many points of view that the function of consulting engineer would form a desirable and important feature in the public service. It is an office called for by considerations of public health and commercial prosperity; it would greatly facilitate the wise direction of public works, and would promote the economical expenditure of the public funds; it would assist the city government to make municipal improvements on sound and broad principles, insuring the greatest good to the greatest number, both in the present and succeeding generations of men. The proposi-

tion to create and maintain such an office should receive the cordial support of every broad-minded and public-spirited citizen, and is likely to be opposed only by those whose sole care it is to conserve petty personal or partisan interests.

The city of Cleveland would have profited greatly in the past from the services of a permanent consulting engineer; for the future his services will be found to be absolutely indispensable.

AVERAGE LIFE OF CROSS-TIES IN STEAM RAILROADS IN COLORADO.

By William Ashton, Member Denver Society of Civil Engineers.

[Read before the Society, January 14, 1896.*]

In renewing cross-ties they are usually gone over but once a year. The portion of track gone over for renewal of ties in the spring is seldom gone over again later in the season, but all ties left in the track at the time the renewals are made are supposed to be good for at least one more year's service.

Most of the ties now used in Colorado are of native pine and spruce. A few oak ties are brought into the state for use under very heavy traffic and on sharp curves, but, by the aid of tie-plates, closer spacing, and better rail-braces, aided by the wider rail-base and stiffer rail, we are now enabled to use pine and spruce native ties at points where their use would have been considered unsafe a few years ago.

When I began railroading it was thought proper to use soft wood ties only on tangents. In looking over some of my old papers I find that in Kansas and Nebraska, as late as 1881, my instructions, when in charge of track-laying on branch lines that were never expected to carry heavy traffic, were to the effect that soft wood ties, such as cedar, cypress, or pine, might be laid in tangents, on 1° curves every third tie must be oak; on 2° curves at least one-half the cross-ties must be oak, and on 3° curves all ties must be of oak. As we had no curves sharper than 3°, I can only guess at what we should have done had we struck an 18° curve. In those days, however, we used only 2640 ties to the mile and 50 to 52-pound rail. Now we frequently use 3200 ties per mile, and seldom less than 2900, while very little new rail is being rolled of a less weight than 65 pounds per yard, if intended for standard gauge track; while the rail rolled in the year 1895 for standard gauge will probably average at least 70 pounds per yard in the West and heavier in the East. While many more ties are used now for a mile of track than a few years ago, I fail to notice a reduction in the size or quality of the different classes. I think the oak ties we get now are fully as good as those we got fifteen years ago, and the same may be said of ties of other woods.

In my opinion, ties are now better cared for than they were,

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and last longer than they did, a few years ago. The increased strength of the rail distributes the weight over a greater number of ties, and much more evenly, than when lighter rails were in use. As a result the ties get less individual punishment under the traffic, even though it has materially increased in weight per lineal foot of train, and although our tracks are subjected to much greater loads and speeds than they were a few years ago. I believe the track has fully kept pace with the increased weight and speed of trains, and is fully as safe as the poorer track was at the slower speeds. I do not intend by this to assert that I believe that our track is entirely satisfactory and good enough for the present traffic, but, while I am fully aware of the unsatisfactory results we get from the present method of track construction and maintenance, of the very primitive manner of fastening the rail to the ties, the weak points at the rail joints, in spite of the almost numberless joint splices and other devices being brought out, yet I feel full confidence in asserting that the track of to-day is as safe and satisfactory, except perhaps from a financial standpoint, as it was a few years ago, when our trains weighed half as much and ran at half the speed; and this safety has been maintained and kept in unison with the increased requirements with the same inferior substructure of wooden ties, supplemented by a few new inventions for increasing their efficiency and possibly somewhat increasing their durability.

Tie-plates are undoubtedly a means of increasing the life of soft wood ties, especially of ties that have naturally quite a long life in the soil, and which were destroyed largely by the cutting and crushing action of the rail where it rested upon the tie. On such ties the tie-plate also aids in holding the track to gauge and tends to prevent the spreading of the rails on curves or elsewhere.

Under ordinary circumstances, my experience on the lines in Colorado, has been that ties of Colorado pine, balsam, and white spruce will last in track $3\frac{1}{2}$ to 4 years under ordinarily heavy traffic. Under light traffic, on a well tied track, they will probably average 4 years. On our main line we usually take out about half of these ties after 3 years' service and the balance the fourth year. On sidings and spurs, where they had very little traffic over them, where no renewals of such ties would be made until the fourth year; yet if, during the third year, this track had been subjected to a fast heavy train, many of the ties would have been found broken and possibly some of them crushed. We have alkali lands where the ties seem to burn out; that is, there seems to be something in this soil that destroys the fiber of the wood, causing it to become worthless in respect both to its tensile strength and to its resist-

ance to crushing. The ties enumerated above often last only two years in this soil.

Yellow spruce, as found in Colorado, lasts in the track about 4 years.

Red spruce is the best of Colorado tie timber. It is a strong, firm wood, holds spike well, and lasts usually 5 years, and in some cases will average 5½ and even 6 years.

Colorado timber, cut at a high elevation, lasts, in some cases, fully one year less than that cut lower down, especially if laid at a considerably less elevation than where it grew. I cannot fully account for this, but it may be in part explained by the fact that the timber grown at a lower elevation has less moisture, grows slower, and is therefore tougher and closer grained.

I think the cost of metallic ties is one of the principal reasons why they are not used more extensively at the present day. To this may be added the lack of uniformity in opinion as to the best form and the absence of any good practical metallic tie. It seems to me that the metallic tie has not yet been taken up seriously enough to make it a success. Trials have been made of different forms of metallic ties, but they usually proved expensive, and at that the railway company would give it up and go back to the wooden tie. If it were not for the old wooden tie to fall back on, we would have metallic ties of a pattern and efficiency that would give little cause for complaint, but I do not look for the general adoption of this kind of a tie until they can be not only furnished at a cost which will compete with wooden ties, durability considered, and until they are made of such form as to admit of their being put in track without having a machinist for a section foreman. I fail to find any reason for expecting that the adoption of metallic ties will materially reduce the cost of track maintenance, except in the matter of renewals of ties, and even with metallic ties, we shall have to keep practically the same kind of track forces as we do now, with perhaps one or two less men on a section during the summer. We will still have to depend on common labor. Therefore we want a metallic tie that can be handled by this class of labor, or a tie that will call for so little attention that we can afford to hire special skilled labor to handle and look after them. We shall require the same amount of lining, ballasting, track raising, widening of banks, cutting of weeds, draining of cuts and other miscellaneous work of this character as heretofore. This work will have to be done by cheap labor, and this labor is what will be called on to put in metallic ties.

ATLANTIC COPPER MINE, HOUGHTON COUNTY, MICHIGAN.

By Theodore Dengler.

[Read before the Denver Society of Civil Engineers, December 8, 1896.*]

In the copper mines of Lake Superior much labor is sometimes expended, as in the Atlantic mine, upon a rock containing low values, but giving a fair earning on the investment.

With one or two exceptions the present producing mines have been in active operation from 25 to 30 years, from which you will correctly infer that they are deep mines, the shafts ranging from 1200 to 5000 feet on an incline. Among the more notable mines are the Calumet and Hecla, Tamarack, Quincy, Osceola, Franklin, Atlantic, Kearsarge and Wolverine, in the order of their output the Calumet and Hecla being the largest.

The mineral beds consist of amygdaloidal traps and conglomerates impregnated locally with metallic copper. The dip of these beds varies from 56° at the Atlantic, the most southerly mine, to 37½° at the Calumet and Hecla mine, 15 miles northeast, and to 26° at the Central mine, 18 miles further northeast.

In the amygdaloidal beds, the copper, as a rule, occurs in an irregular manner, in the form of chutes and pockets requiring much dead work in finding and opening out the rich ground. The Atlantic lode is a single exception. Here, the copper being evenly distributed, little dead work is required and the whole bed is stoped. In conglomerates, the copper is generally very evenly distributed.

The region has been a study for geologists as much as that of Cripple Creek, if not more. Dr. Wadsworth, the former geologist of Michigan, now president of the Michigan Mining School, in speaking of the Calumet and Hecla mine, says: "This famous mine has as a lode an old sea beach conglomerate which is underlaid by a lava flow as well as overlaid by one, and the copper has been chemically deposited within this conglomerate by the percolating waters long subsequent to its formation, and after it was deeply buried under successive lava flows. Although many speak of the Calumet 'vein,' neither that mine nor any other in the Portage Lake division is worked upon a vein or upon anything that in the slightest degree approaches a vein in its character. All are bed mines."

*Manuscript received September 13, 1897.—Secretary, Ass'n of Eng. Socs.

This gives you the why and wherefore in a nutshell, and is the prevailing idea in the minds of most scientific men who have had occasion to be on the lookout in the district.

In the foregoing statement the term "bed mines" does not include some of the mines at the northeast end of the region, which have been closed down. They were worked on "true" fissure veins lying across the beds which I have mentioned at about 90° and have become impoverished with depth. The veins produced chiefly mass copper, the masses varying in weight from a pound to several tons, with some mill rock. The largest mass I have heard of was found in the Central mine. Its total weight was given out as about 600 tons, and no little labor was required to reduce it to shape for handling. I am told that 2 years were required to remove it in pieces small enough to go into a reverberatory furnace. A piece of this mass was on exhibition at the Chicago World's Fair in 1893. At present we hear of but few very large masses in bed mines, and, when they do appear in the working mines, they sometimes cost more than their worth to extract them. The only practical means for reducing masses is with cold chisel and hammer. Prices as high as $10 per square foot of cut have been paid for this work to experienced men.

The largest producer of native copper is undoubtedly the Calumet and Hecla mine, which produces a minimum of 3000 tons of refined copper a month. The Anaconda mine in Montana exceeds this output, but its product is from copper ores containing a high percentage of copper.

The Calumet has the largest machinery and the deepest shafts of any mine in the world. It is working upon a conglomerate carrying about 3½ per cent. of copper. There are twelve shafts, the deepest being a little over 5000 feet on the incline, while the latest undertaking was to put down a six-compartment shaft measuring 20 x 15.5 feet over all, 4900 feet vertically, through dead ground, from which cross-cuts have been made to the lode. This shaft cut the conglomerate at 3300 feet.

The total horse power of the boilers at the mine and stamp mill, commercial standard, is 22,422.

The aggregate horse power which can be developed by the engines belonging to the company is 40,000. A notable feature to be observed at the mine and mill is that the hoisting engines and pumps are arranged in pairs. Should an accident happen to the engine in use, the duplicate engine can immediately be put into operation.

The company employs some 3456 men.

About a mile northwest, on the hanging wall side of the Calumet and Hecla conglomerate, the Tamarack Mining Company is sinking a shaft 7 x27 feet, which is expected to cut the same conglomerate at a vertical depth of 4600 feet. The lode at this mine is very wide, about 22 feet, twice as thick as the conglomerate usually is. The company has four shafts in operation, with depths of 3234 feet, 4290 feet, and 4393 feet, respectively. About 1426 men and boys are employed at the mine and mill.

At most of the mines the men are lowered to the work by means of skips or a man-engine, but at the Quincy mine there is an attractive feature in the rapid handling of men. Formerly they were sent in and out of the mine on the old-fashioned time-consuming man-engine; they are now lowered and raised in a man-car, and the entire force underground, about 400 souls, can be got in or out of the mine in thirty minutes. The man-car bears a close resemblance to a flight of stairs, the under side of which is provided with wheels that rest upon the shaft track. There are banisters on this section of stairs to prevent the men from being crowded over the sides. The men take their seats on the steps and are gently lowered into the earth a distance of 4000 feet on the incline. Thirty men are carried at a load. The change from the man-cars to the skips is made at each shaft in less than 2 minutes. Two 5-ton cranes are placed in each shaft house, one on each side of the skip road, and with these the man-cars are lifted off, and the skips substituted in the time given.

While the Calumet and Hecla and other mines carry the distinction of being big producers, no little attention has been directed to the Atlantic mine by reason of the excellent results achieved in its operation.

This mine is situated about 3 miles southwest from the town of Houghton, and 8 miles inland from Lake Superior. It is working upon an amygdaloidal trap extending N. 52° E., dip 56°, and with an average thickness of about 10 feet. The rock yields about 0.73 per cent of refined copper or 14.6 pounds per ton of rock treated. At 10.52 cents a pound (which the management realized 1895) this amounts to $1.5352 for the average value in every ton of rock treated. This is the smallest percentage of copper per ton of rock that is being worked in the district with profit, other mines having all the way from 1.5 to 3.5 per cent.

With this small value in the rock, the company managed, in 1895, to earn a gross profit of $110,600. The ground broken and the product for the year were as follows:

Extract from Mine Report for 1895:

Ground broken in openings and stopes................	20,037 fathoms
Rock stamped	331,058 tons
Product of mineral	6,239,000 pounds
Which gave a product of refined copper.................	4,832,497 "

The expenses were divided as follows:

Cost per ton of mining, selecting and breaking, and all surface expenses, including taxes	$0.7525
Cost per ton of transportation 8 miles to stamp mill	.0408
" " " " stamping and separating	.2220
" " " " freight, smelting and marketing product, including New York office expenses	.1881
Total cost per ton of running expenses......................	$1.2034
Gross earning per ton of rock treated	$0.3318

In 1894 the yield was 14.06 pounds of copper per ton of rock. Receiving a gross value of $1.3376 for the copper in a ton of rock the mine managed to earn $48,763.

The company employs about 450 (?) men and boys at the mine and mill. The management strives, above all things, to keep the skips in the four shafts hoisting rock; and, barring an occasional accident, the skips are in continuous travel from 7 A.M. to 5 P.M, and again from 7 P.M. to 5 A.M., stopping a few minutes at 12 o'clock for oiling up. The interval of two hours between shifts in the morning and evening are devoted to the hoisting and lowering of men, stulls and lagging. Engines, cars and skips are oiled and greased, fires are raked and everything is put in order for the next shift.

A miner or trammer, failing to be on hand to go down or up in this interval, will find it necessary to climb a few thousand feet of ladders or else risk his life in jumping for the skip while it is in motion. Though the latter is often done, the offender is liable to be discharged if discovered in the act by an official.

The hoisting plant at each shaft is in charge of an engineer and a boy, the latter attends to the firing and feeding of the boiler at the command of the engineer, the boiler being in full view of the engineer.

Most of the trammers are Findlanders. The miners are mostly Cornish. Boys, generally the sons of miners and laborers employed about the mine, are used where possible in engine houses and the stamp mill at $18 to $20 per month.

Miners' wages average about $52 to $55, and trammers receive from $38 to $45 per month.

The district, being in communication with the East both by rail and water, has the advantage of low freight rates. Especially is this the case with coal. Vessels which carry iron ore and lumber from points on Lake Superior to Cleveland, will take on a cargo of coal at Cleveland, charging a small rate rather than return light with no profit. By this means good Ohio soft coal is laid down in Houghton at about $2.25 per ton.

The Atlantic also receives good sound maple cord wood along its railroad.

The mine and mill consumed $77,314.75 in coal and wood during the year 1895.

There are four shafts, the deepest being 2150 feet on the incline. The hoisting engine at each shaft is assisted in its work by a "dummy" of cast iron which travels up and down on a small track alongside the skip road. Being of about the same weight as the rock in the skip, 3000 pounds, it affords a partial balance to the engine.

The mine is opened out laterally about 4800 feet. All mining is done on contract. The prices paid range from $5 to $7 per foot drifting, $7 per fathom for stopes and $20 for shaft sinking. The net cost to the company is probably less than this, as these are prices upon which miners have always based their bids when dynamite was more expensive than it is now, and the company furnishes the explosive at the former price, reserving the profit due to the variation and present lower price of the dynamite.

The company furnishes Little Giant Rand drill machines, of which there are 28 in operation, and makes all repairs to the machines.

Compressed air is delivered to within 50 feet of the working place by iron pipes. All other items, such as bits, powder, airhose, etc., are charged to the miner. Bits are sharpened by the company's blacksmith gratis to the miner. The ground broken in the mine is about six months in advance of the tramming, and would run the mill for that length of time should anything cause the mine to close down.

Tramming is done on company account, a trammer receiving from $38 to $45 per month for 10-hour shifts.

The water in the mine is removed by a Cornish pump from No. 3 shaft towards which all the water in the mine is drained.

The rock is hoisted in skips weighing 4500 pounds, with a capacity of 3000 pounds, traveling at an average speed of 750 feet per minute.

The four shaft-houses are connected by a trestle, over which

the rock is transferred by rope haulage to the rock or crusher-house at one end of the property. Herein all the rock is crushed in Blake rock breakers, to pieces about the size of one's hand and smaller. Any small masses which appear are picked out and sent direct to the refinery. The crushed rock falls into bins, from which it is transported by rail to the stamp mill a distance of 8 miles. At the mill, the rock is further reduced in size, in 18 inch steam stamps, having a capacity of 250 tons each day. The shoe on these stamps weigh, when new, 700 pounds, and lasts about 18 days, its weight having been reduced by that time to 250 pounds or less. The stamped material is washed through 2 screens, with meshes or slots $\frac{1}{8}$ inch by $\frac{1}{4}$ inch, placed at either end of the mortar. Thence the material is passed over a hydraulic separator, which separates it into particles of five different sizes, four of which pass through Collum jigging machines, of which there are fifty-six to each stamp head. The fifth or smallest particles, called slimes, are run over revolving slime tables and thence to keeves. The resulting product of the stamp mill averages 76.46 per cent. of pure copper. This is put into barrels having a capacity of about 1200 to 1600 pounds. The barreled material is taken back to the mine by rail, and teamed to Houghton smelters, a distance of 3 miles, where it is refined and cast into ingots, bars or plates, and then shipped East.

The water used in the milling process is obtained from a river near by, across which a dam has been constructed of timber, loose rock and sand. The main portion of the dam is a crib-work built up with hewed hemlock 14 inches thick, securely bound at the joints with 1 inch square drift bolts 30 inches long. The dimensions are: height 48 feet, length at the top 258 feet, length at the bottom 81 feet, width at top 28 feet, and width at the bottom 53 feet, with a perpendicular face up-stream and slope down-stream. The up-stream side of the dam is planked with two layers of boards, one of 3 inches inside and one of 2 inches outside. The crib-work was filled with sandstone, obtained from the banks nearby, while a sand filling was put in front of the planking. A few months after the dam had been filled, it was found to have settled about 10 inches in the center; and the face, which was originally straight across the stream, had curved, at the top, 3 feet down stream. Since then, no perceptible movement has shown itself.

The water is conducted to the mill in a launder 18 inches by 36 inches and 2050 feet long, with a fall of 5 inches in 100 feet. At the mill, the launder discharges into a steel tank 8 feet in diameter and 10 feet deep. A 30 inch cast iron pipe leads from the bottom

of the tank and passes under the floor of the mill, where it is tapped at intervals for supplying the jigs and stamp heads.

This water supply is of the greatest importance to the company, as without it, the chances are that the company would have to suspend operations. When it is taken into account that about 30 tons of water are used in the washing of a single ton of rock, and that this company treats from 1100 to 1200 tons of rock daily, it would be out of the question to lift this large bulk of water with a pump, where the value in the rock is as low as it is at this mine.

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THE 40-INCH TELESCOPE OF THE YERKES OBSERVATORY.

BY WM. E. REED, M.E., MEMBER THE CIVIL ENGINEERS' CLUB OF CLEVELAND.

[Read before the Club, July 13, 1897.*]

SOME years ago the University of Southern California, desirous of having a telescope still larger than that of her sister institution, whose observatory was given by Mr. Lick, ordered of the late Alvan G. Clark an object glass which should have a clear aperture of 40 inches, the largest refracting objective attempted up to that time.

Shortly after the order was placed, Mr. Clark visited, in Paris, the works of Mantois, who—partly as the successor of Feil, but largely on account of his own skill in the art—had become so successful and famous as a manufacturer of optical disks, especially of the largest sizes. Here he picked out, from the glass castings which had comprised a portion of Mantois's exhibit at the Paris Exposition in 1889, a crown and flint disk, in his judgment the most perfect to be had. These disks, however, were not destined to be finished for this University of the Pacific Slope; for, soon after the order was placed, both the president of the University and the patron who had offered to provide the glass died, so the lenses remained in statu quo at the works of the Cambridge maker for some time. The train of events, which finally resulted in securing them for the University of Chicago, is not without interest, for it is only another illustration of the fact that often

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seemingly trivial incidents are really important links in history's chain. Mr. Clark was attending a meeting of the American Society for the Advancement of Science, held in Rochester, and in conversation with Professor Hale—of whose great interest in astronomy he was well aware, from the results already attained at the latter's own private observatory at Kenwood—mentioned the disks that were still in his possession, and spoke of his desire that some University, that could put them to the best use, should have them finished and suitably mounted, in order that they might be of service in advancing the work of American astronomers. On his return, Professor Hale sought an interview with President Harper, of the University of Chicago, who was much interested in the subject, and together they laid the matter before Mr. Yerkes, with the result, as is well known, that the lenses were purchased, and Mr. Clark was instructed to finish them in the most perfect manner possible. Mr. Yerkes also entrusted the contract for a suitable mounting to carry these precious bits of glass, to Messrs. Warner & Swasey, of this city, whose mounting of the largest refracting telescope until then constructed (the 36-inch on Mount Hamilton) had already been demonstrated a complete success.

The contract for mounting this instrument was given late in November, 1892, and, although at that time there was not a scrap of drawing made toward its design, yet by special effort the instrument was gotten out, and, as many will remember, was exhibited in the main aisle of the Liberal Arts Building at the World's Columbian Exposition in 1893. The lens, of course, was not finished at this time; and, in fact, some of the smaller details of the instrument itself were not completed; yet it was set up in working order, much to the delight of those who were interested in astronomical matters. Neither was the final location of the instrument determined at this time, although it was decided that the observatory should be within a radius of 100 miles from the University of Chicago, and probably in a direction northward. It was of the utmost importance that a place should be found not only sufficiently far away from the smoke of the city and the glare of its lights, so that these elements should not interfere with the observations to be made with the new instrument, but also at a safe distance from the encroachment of the growing city in years to come.

A number of prominent observatories have been located on mountain tops, notably the Lick on Mount Hamilton; and it is often asked whether it is not essential that such centers of astronomical investigation should be placed on similar elevations. While

a mountain has its advantages for such a site, it also has its drawbacks, chief among which is the atmospheric disturbance, caused by the different degrees of temperature to which the air on the opposite sides of the mountain is heated. The reason is obvious, for the sun shines more intensely on one side, heating that surface most, and causing the air above it to rise more rapidly than on the other sides. At the summit it comes in contact with the cooler air, giving rise, at once, to an atmospheric disturbance of no small consequence, which, in certain classes of work, is prohibitive of useful results, and in most cases renders the use of the instrument out of the question for solar observations. Were the location of such an observatory, however, in the midst of an extended plain, the disturbance caused from differently heated vertical strata of air would be very largely done away; and, of course, the matter of a few thousand feet of elevation more or less is of little importance, except that in some cases it takes the astronomer into a region of sky less frequently clouded, or removes him from local disturbances, such as artificial light, dust particles, smoke, etc.

The site finally chosen for the location of the 40-inch equatorial has many of the advantages of a plain. It is situated on the edge of the Big Foot prairie, so named by the Indians, and on the north bank of a small and picturesque lake in the southern portion of Wisconsin. The shores of this lake have for years been dotted with the summer homes of people from the large cities near by; and the location, in all probability, is destined to be always removed from large manufacturing interests. The observatory is about 75 miles northwest from Chicago, on a hill 240 feet above the lake, and 1200 feet above the level of the sea. It is a mile and a half from the village of Williams Bay, which is the terminus of the nearest railroad, and that is but a branch of the Northwestern system. There are no arc lights to disturb the observations of the astronomer, nearer than those of the town of Geneva, which is at the opposite end of the lake, a distance of 8 or 9 miles.

The general arrangement of the building itself—which, with its appointments, is also the gift of Mr. Yerkes to the University of Chicago—was suggested by Professor Hale, the present director, who had spent considerable time in visiting prominent observatories, both in this country and abroad. The designs were given to Mr. Henry Ives Cobb, whose Fisheries Commission Building at the World's Fair will long be remembered, and by him were brought to a most successful architectural issue, without in any way detracting from those purely scientific features, which the

astronomers were so anxious to retain. In general, the building is arranged in the shape of a Roman cross, the long axis being east and west, and having a length of 326 feet. At the west end of the building is the immense tower and dome which houses the great star searcher. At each end of the arms of the cross—which are at the eastern extremity—are small domes for 12-inch and 16-inch telescopes, respectively, while the central portion of the eastern end is designed especially for a large meridian circle room. The arms of the cross extend relatively a considerable distance from the rest of the building, so that the great dome will not prove a serious obstacle to observations in the western heavens from the smaller towers.

The observatory is built of brown roman brick, and ornamented with decorations of the same color in terra-cotta. The pillars, which figure so prominently in supporting the archway of the beautiful central entrances—just alike on both sides—suggest those of the Fisheries Commission Building, in the clever use the architect has made of the grotesque in ornamentation. The central portion of the building is but a single story high, though a large attic extends its whole length, and a well-lighted basement is available for laboratories, and for a machine shop for the construction and repair of such instruments as may be needed at the observatory. Besides these, there are also, in the basement, rooms especially adapted for the necessary photographic work, which has come to occupy so large a place in modern astronomical research. The main floor is divided longitudinally by a beautiful hallway with mosaic floor and marble wainscoting, and is occupied by the director and his staff for offices. There are, besides, some small laboratories, and a well-appointed library, which commands an exceptionally fine view of the lake, and makes an ideal place for quiet study.

As the subject of this paper is more especially connected with the contents of the west tower and dome of the building, a word or two regarding this portion may be of interest. The tower itself is 92 feet in diameter, and is built of masonry to a height of 52½ feet. A balcony, 44 feet from the ground, commands an extended view of the surrounding country, and, together with the special relief work of pillars and arches just below, adds greatly to the beauty of this imposing structure. The dome which surmounts it is 90 feet in diameter, and, contrary to the pattern followed at some other large observatories, a cross-section shows that the dome, while a hemisphere above the plane which includes the center of motion of the instrument, is cylindrical below it for a

distance of 9 feet. This additional height greatly improves its appearance, doing away with the flat and squatty effect which is so evident in domes that are only hemispherical. The frame throughout is steel, and is built up of latticed girders riveted to an immense horizontal circle, also of lattice construction. The dome is supported by 26 wheels, practically of the size and shape of ordinary car wheels without the flanges, and their axles run in special anti-friction roller bearings placed on each side of the wheels. The outside of the journal boxes is spherical in shape, and held in pillow blocks to correspond, thus allowing for self-adjustment and preventing their cramping. The wheels run on 90-pound T rails, which are held on a circular cast-iron supporting ring anchored to the masonry walls.

The dome is covered with wood, tinned on the outside and painted. Instead of the covering being bent to conform to a true spherical shape, the wood work is put on straight; that is, sections through the dome, perpendicular to its axis of rotation, are not circles, but polygons of twenty-two sides each, the corresponding sides of such successive sections being shorter as they approach the zenith. These tapering panels—which do not materially change the shape of a dome from a spherical form—improve its appearance, and provide a more tasteful and satisfactory form of construction. This great dome weighs, complete, 140 tons, and is easily revolved by means of an endless cable, which connects it with the operating mechanism. A circle, nearly of the diameter of the dome itself, made of angle iron, with the inner leg vertical and the other horizontal—forming thus, as it were, a flanged pulley—is secured to the lower inner edge of the dome, and in its groove rests the endless steel cable, which wraps almost entirely around its circumference. At one point, however, the cable is led off and back again tangentially by means of guiding sheaves, from which it runs to the operating mechanism below. This controlling device, carrying with it the great dome, is easily set in motion, either by an electric motor or by a hand rope conveniently placed so that the operator has access to it from the elevating floor, or from the upper balcony.

It is necessary that the dome should be made to revolve, in order that its shutter opening may be brought to a place opposite the objective end of the tube of the great telescope, in whatever position that may be; and to make a dome with a large parallel opening 12 feet wide, extending from the horizon to a point 5 feet beyond the zenith, and to provide for easily opening and closing the shutters which cover it, adds not a little to the interest and

intricacy of the problem. To provide the necessary stiffness for the dome with this opening, two latticed girders, much larger and heavier than the rest, extend from the base ring through the zenith to the base again, parallel to each other and equidistant from the center. These girders are 2½ feet deep at their extremities, and 4 feet at the zenith, and into these great vertebræ the other ribs are fastened, instead of meeting in the zenith, as would be the case were there no shutter openings in the dome. At the base of each of these immense girders are placed trucks, with two wheels instead of one, as is the case elsewhere, for it will readily be seen that the greater portion of the weight of the dome rests at these points. The two shutters, which cover this space, open from the center outward, and are 85 feet long. They are supported on tangential tracks at their extreme upper and lower ends, and they, too, run on wheels with anti-friction bearings, working so easily that a direct pull of 75 pounds will move them. In practice, however, both shutters work simultaneously, and are maintained parallel to each other throughout their entire travel by special mechanism. These great doors are operated by means of a hand rope conveniently placed, and a direct pull of a few pounds only is required to open or close them, though they weigh 9 tons each.

A unique accessory to the shutter—and one which will no doubt be much in use—consists of two canvas curtains which run independently of each other on tracks just underneath the shutter opening and inside the dome. The curtains are placed end to end, their combined length being greater than that of the shutter, and their breadth a trifle greater also. Light and strong steel stays are placed crosswise of the canvas, throughout its length, at frequent and equal intervals, and terminate at each end in trucks, each having two wheels which run upon the special track provided for them. As each curtain can be moved up and down without interfering with the other, and then clamped, it becomes a simple matter to bring the upper curtain to such a place that it will cover the portion of the opening above that through which the great objective is peering, and the lower one till it covers all below it, thus shutting out wind, light and other elements of annoyance to the astronomer, from practically all that part of the opening which is not actually in use.

Having looked somewhat hurriedly at the general arrangement of the building and the outside of the dome, let us now turn our attention within.

The inside of the tower is one great circular room, which one enters upon a level with the elevating floor in its lowermost posi-

tion, reaching it from the broad hallway of the main building by a beautiful marble stairway. At this height there is also the lower of the two balconies, which extend entirely around the inside of the dome, making, when the elevating floor is at its lowest or uppermost position, a continuous floor, 85 feet in diameter. The lower balcony is 21 feet above the basement, and the one above is 23 feet higher, the latter being reached by a narrow iron stairway from the lower balcony, and a similar one also leads down to the basement. The upper balcony is on the same level with the one outside, to which we have already referred, and easy access from one to the other is had by means of four doors with glass sash. There are, however, comparatively few windows in the tower, 4 at the level of the upper balcony, 16 just above the lower balcony, and 13 narrow windows near the ground floor.

One of the most important accessories within the dome, aside from the instrument itself, is the great elevating floor. This is circular in shape, 75 feet in diameter, conforming, with slight allowance for clearance, to the inner diameter of the balconies. In its center, or practically so, is a rectangular opening, of such size that, as the floor moves up and down, it nowhere touches the telescope column. The necessity for having the floor rise and fall is obvious, when one considers that from it the astronomer makes his observations, and that the height of the eye end of the instrument when pointing to the zenith is very different from that when the telescope is directed to points near the horizon. In smaller observatories an observing chair, arranged somewhat like a broad stepladder, and having a sliding seat in the central portion, answers every purpose; but, with so large an instrument as this, it is not only necessary to have the observing chair, but, in addition, to cause the floor to rise and fall, in order to give the observer easy access to the eye end of the instrument. The highest position to which the floor rises is on a level with the upper balcony, and its lowest position is at the same height as the lower balcony, thus giving it a movement of 23 feet. In its uppermost and lowermost positions, it is readily reached from the balconies. For intermediate positions, the stairway, which connects them, and which is at their outer edge, furnishes a convenient means of access to it. The floor is built of latticed steel girders in the shape of a square, which together with the necessary cantilevers, support the practically circular I beam which forms the edge. The girders are covered with pine flooring, laid on spiking strips, and finished with an oiled maple floor, the whole being suspended by steel cables from each of the four corners of the square steel frame-work. These

cables run over sheaves at the top of the latticed columns, in which run the counterweights, and to them the other ends of the cables are fastened. For raising and lowering the floor, cables are run from the operating drums to the under side of the counterweights, and from the same drums to the under side of the floor at each of the respective corners of the framework, thus allowing the floor to be balanced as nearly as possible, since the operating mechanism will either pull the weights down when it is desired to raise the floor, or will pull the floor itself down, in case it is to be lowered. The drums are revolved by worm gearing, and all four of the worm shafts themselves are brought, by means of shafting and bevel gearing, to a common point near the center, where they are operated by a single motor. In this way, the position of the floor is maintained parallel to itself throughout its entire motion, and, owing to the counterbalancing, the motor has little to do beside overcoming the inertia of the moving parts, though the weight of the floor is 45 tons.

Both the floor and the dome above it were designed by Messrs. Warner & Swasey, the execution and details of their plans having been most excellently carried out by the King Bridge Company of this city.

In the center of this great tower rise the pier and column of the telescope. The pier is built upon a concrete base 28x34 feet, 5 feet thick. It is of brick work 20x24 feet at the base, tapering to 15½x19½ feet at the top, where it is capped by an immense stone coping in four pieces, 18 inches thick, the capstone being 21 feet above the concrete base. Upon this rests the cast-iron column, which is made in five sections, exclusive of the head. The lower section differs materially in shape from the others, and, in fact, is the only one not cast in a single piece. It provides a broad base, tapering by easy and graceful curves in a height of 5 feet from 14 feet by 18 feet at the bottom, to a rectangle 6 feet by 10 feet 4 inches, on which rests the upper and straight portion of the column. The slope of the base is not equal on all sides, however, owing to the fact that the tube and axes above bring the center of gravity much nearer the north end of the column than the south, and the base is, therefore, much broader on this side. It is not only strongly ribbed vertically, but there is a solid support under the portion on which the column rests, extending to the very capstone, and thus securing for the column the greatest rigidity. The upper sections of the column are rectangular cast-iron shells, each about 6½ feet high, and tapering ⅝ inch per foot. The center of motion of the instrument, in the head which surmounts the column, is 43½ feet above

ENGIN'G

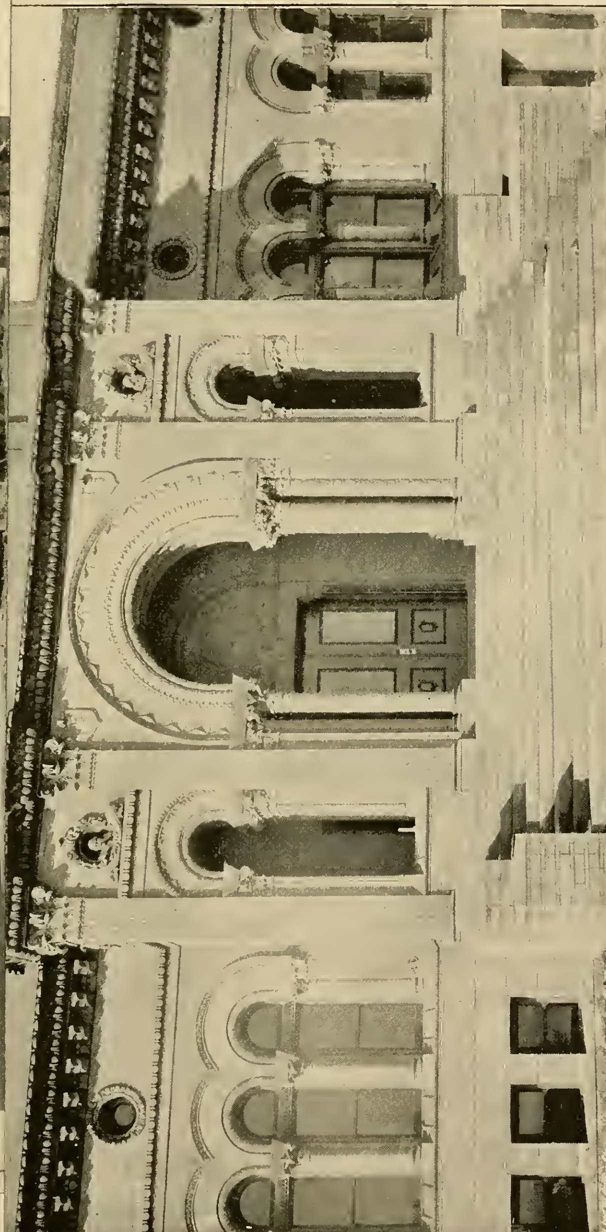

Fig. 3. Main Entrance to the Yerkes Observatory.

FIG. 1. THE YERKES OBSERVATORY.

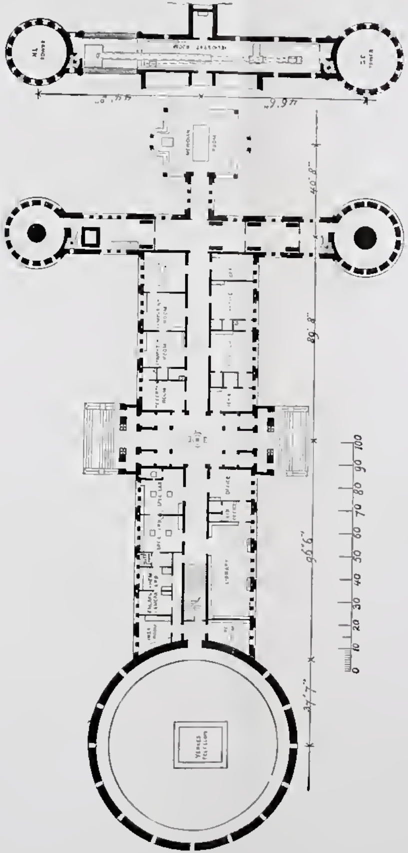

FIG. 2. MAIN FLOOR OF THE YERKES OBSERVATORY.

FIG. 3. MAIN ENTRANCE TO THE YERKES OBSERVATORY.

the coping-stone of the pier. At the south end of the column is the spiral staircase, extending from the capstone to the balcony around the equatorial head, there being also a landing at the upper section of the column, in which are the driving clock and other accessories.

Having now noticed the supporting column of the great telescope, and its location in the building, let us turn our attention for a moment to that which makes necessary the design and construction of this great astronomical engine—namely, the objective itself. This portion of the instrument is often surrounded with so great a halo of wonderment, emanating chiefly from the imagination of such newspaper writers as are not altogether familiar with its use or construction, that not a few of us are at a loss to know what it is lawful to believe, and what is purely fiction. It may, therefore, be of interest to speak briefly of the lens itself, and of its transportation to the observatory. As has already been widely heralded, the lens and cell were brought from Mr. Clark's factory at Cambridgeport, Mass., in a Pullman car. They were the contents of three large boxes about 5 feet square, and from a foot to 18 inches thick. The smaller boxes contained the lenses and the larger one the cell, in which they were to be held. The objective is composed of two lenses, a crown and a flint. The crown lens is double convex, and is $2\frac{1}{2}$ inches thick at the center, and $\frac{3}{4}$ inch thick at the edge; while the flint, which is practically plano-concave, is 2 inches thick at the edge and $1\frac{1}{2}$ inches at the center, both lenses being $41\frac{1}{2}$ inches in diameter. Each lens was wrapped in the finest and heaviest felt, which was sewed around the circumference, and then covered with tough wrapping paper, glued at the edges to prevent dust and dirt from working on to the surface of the glasses themselves. These parcels were packed in the boxes referred to with an abundance of curled hair, some of which had served a similar purpose in the transportation of the Lick objective, but—newspapers to the contrary notwithstanding—there were no springs for supporting the lenses other than the abundant mass of spirally curled hair. The cell is a cast-iron ring, flanged at the inner edge, and has a corresponding flange at the outer edge. The portion of the ring between the flanges is perforated with seven equally spaced elliptical holes, to allow for ventilation and for cleaning the lenses; but a circular band or shield of brass is so arranged that these ventilators are easily opened or closed at will. The glasses, when placed in the cell, are each supported at three points on aluminum bearings, and are separated by a distance of $8\frac{3}{8}$ inches. After the lenses were unpacked and were carefully dusted with a camel's-hair brush, and

after the operator had wiped them clean with a fine cotton cloth, breathing on them now and then to supply a little moisture, Mr. Clark asked three or four of the gentlemen present to carry them in their hands and place them upon the simple and ingenious jacks which were provided for lowering them into the cell. Mention is made of this trivial fact, because one often reads—in the ever-present newspaper—of the ruinous effects of barely touching optical work.

The cell and its lenses weigh about 1000 pounds, and to support this precious weight rigidly, and to make provision for observing and for magnifying the real image which it brings to a focus 61 feet away, as well as to enable the astronomer to point it at will to any object in the heavens, is the problem that confronts the engineer; nor is this all, for jarring and vibration vitiate observation, and from these the instrument must be free. To support this cell and its lenses, a great tube is made, 59 feet 3 inches long. It weighs six tons, and is built up of sheet steel in five sections, or four tubes of nearly equal length, and a central one which is short, but very strong. Each section terminates in a steel flange, faced true, thus furnishing means for bolting the several tubes together in accurate alignment. All rivet holes were drilled, the steel plates being bent about special forms for the purpose. The central section is 52 inches in diameter, and from it the tube tapers slightly, in both directions. It not only has the steel flanges at the edge, but several steel rings inside to stiffen it, and to provide means for attaching it to the declination axis.

The cell is bolted to the corresponding flange at the end of the steel tube by means of six bolts, arranged in pairs, each pair being equally spaced with reference to the others, around the circumference, and between the two bolts of each pair is an abutting screw, so that the cell actually rests on three points, thus bringing the least possible strain upon the lenses themselves, and providing accurate collimation.

The declination axis, to which the tube is bolted, is held in an immense sleeve of cast iron, which, in turn, is bolted to the upper end of the polar axis, at right angles to it, and at a position as near to the tube as possible, so that a minimum weight at the end of the declination axis shall, with its long leverage, balance the weight of the tube about the polar axis. To accomplish this, a long brass screw, with heavy steel center, is fastened to the end of the declination sleeve, and carries circular cast-iron weights of about 225 pounds each, which can readily be moved backward and forward upon it, to allow for changes in the weight of the acces-

sories used upon the tube itself. The polar axis is held in immense bearings in the equatorial head of the column, and its angle of inclination corresponds exactly to the latitude of the observatory where it is located.

The polar axis has no motion except one of rotation in its bearings, but the declination axis, which is at the upper end, not only has its motion of rotation, carrying with it the tube, but is itself rotated about the polar axis. Thus it will be seen that the tube has two distinct motions, one on the declination axis, which is nearly midway of the length of the tube and at right angles to it, and the other on the polar axis, which carries the declination axis and the tube. Since the polar axis is parallel to the axis of the earth, it is evident that if it is given an angular motion equal to that of the earth, and opposite to it in direction, any portion or extension from it will maintain unchanged its position relative to fixed bodies beyond our sphere; and, the axis being fixed, it becomes a simple matter to fasten to it suitably a large worm wheel, and to drive the worm by clockwork, thus giving the tube a motion corresponding to that of the earth. To drive the instrument at such a rate does not require very great power, even though it has to move a mass of 20 tons, for it turns it at the rate of but one revolution in a siderial day of 23 hours, 56 minutes, 4.09 seconds.

Both of the axes of which we have been speaking are made of steel, the polar axis being 15 inches in diameter, 13½ feet long, and weighing 3½ tons, while the declination axis is 12 inches in diameter, 11½ feet long, and weighs 1½ tons. They are both hollow steel forgings; for, in order to secure the necessary automatic motions of the tube, to be described later, shafts transmitting this motion must be brought through their centers to the necessary gearing.

Both axes are held in great babbitt bearings; but, to relieve them from unnecessary friction, live rings, or anti-friction roller bearings, are so arranged that they take the greater part of the weight, the babbitt boxes serving chiefly the important part of maintaining the axes always in their proper positions. The roller bearings for the larger (polar) axis can be adjusted once for all, since its position is fixed, but in the case of the declination axis these roller bearings must support the weight for positions which are constantly changing. To arrange for this, an ingenious system of compound levers is provided, which not only supports the weight through a plane, but in any position through 360°. By

compounding the levers, the necessary actuating weight is reduced to a minimum.

The clock which drives this instrument is placed in a section just below the head; it is driven by a weight of about $1\frac{1}{2}$ tons, suspended by a steel cable from a grooved drum. This drum, by means of the necessary gearing and shafting, revolves the worm, to which we have already referred, and it in turn revolves the worm wheel fastened to the polar axis. The clock is governed by a double conical pendulum mounted isochronously, and the balls of the pendulum are so arranged that rotating them on their axes furnishes a means of slightly altering the speed of the clock; but, after the proper rate is once found, it is rarely necessary to change them, for the gearing is in triplicate, so that either solar, lunar or siderial time can be secured by making the proper change. To do this, it is necessary only to turn a lever to the proper position on a dial. The clock weight can easily be wound by hand, but an electric motor, so arranged that the weight cable operates its switch, starting it when the clock is nearly run down, and stopping it just before it is fully wound up, is still easier and less liable to be forgotten. This form of clock governs the speed of the instrument with wonderful exactness, and that under great changes, since it must readily maintain its own speed constant, either when merely running alone, or when carrying the whole movable mass of the instrument, for during the astronomer's observations, the clock must be ready at any instant to keep the telescope pointed to the object which he wishes to follow.

Simply to mount a mass of 20 tons, distributed as this is, so that the observer, at the eye end of the tube, should be able to move it at will to positions within the range of his reach, would be a comparatively easy task; but much more is required. The observer must be enabled readily to point the objective to the zenith and again to the horizon, either on the east side of the column or on the west, and the various positions through which the eye end travels, ere it reaches the desired location, are such that it would be impossible for the observer to push and pull the big tube through more than a limited space. For this reason, there are placed at the north end of the column, where they can be easily reached by an assistant standing in the balcony, two hand wheels which resemble those in the pilot box of a small yacht. By means of shafting and gearing, a few pounds' pressure on one is sufficient to turn the tube on the declination axis in either direction; or, by turning the other wheel, motion is given to the tube on the polar axis, so that, from the balcony, one can at will point the great tube

toward any portion of the heavens; and, for his aid in so doing, coarse and fine circles are provided on each axis indicating the degrees and hours—celestial latitude and longitude—of the space toward which the tube is pointing. In addition to these "quick motions," by hand, two electric motors, which are placed in the clock room, are so arranged, by special gearing, that they will also move the tube in either direction on either axis. Reversing switches, especially designed for the purpose, are placed near the hand wheels in the balcony, where they can be easily operated by the assistant, or by a special device from the elevating floor. These switches are provided with stiff springs, in such manner that when the operator releases his grip, they automatically throw out. Resort was had to this device, lest otherwise the motors might some time be left running and carry the tube too far.

The motions thus far mentioned, except that of the clock, are for rough-setting the instrument; that is, for pointing the tube approximately to the desired spot. When this has been found, the tube is clamped in position; that is, by devices not yet mentioned the tube is fastened to the declination sleeve, so that it no longer turns freely on its axis, and the polar axis is clamped to the worm gear, driven by the clock. It, therefore, remains for us to describe the slow motions by which the operator brings the object into the center of the field.

This mechanism is the same in both right ascension and declination; therefore, let us confine our attention to that in declination.

A large ring, the inner edge of which is wedge-shaped, fits into a corresponding groove on the declination sleeve, the groove being in a plane at right angles to the axis and near the tube end of the sleeve. From one side of the ring there projects a long triangular arm, the base of which is attached to the ring, and the apex terminates in a suitable device for holding a special bronze nut. On the tube, two brackets support a bronze screw, which passes through this nut, thus connecting the lower portion of the arm with the tube, though in such a way that, if the arm were held stationary, the tube could be given a slight angular motion with relation to it, by moving the nut along the screw; but, when the arm is not held fast, the ring turns freely in its groove, allowing the tube to turn on the declination axis, carrying the ring and arm with it. Since the sleeve, on which the ring revolves, is stationary with reference to the declination axis, it is not difficult to clamp the ring to it. To accomplish this, a few inches of the wedge-shaped portion of the ring are cut away, and a movable bronze wedge is substituted. A screw forces the wedge forward, clamping the ring

to the sleeve, and shafting and flexible joints connect the screw with a hand wheel at the eye end of the instrument, so that the observer can readily operate it from that point. A precisely similar arrangement allows him to do the same for the polar axis, although, in that case, as already mentioned, the ring is clamped to the worm wheel, which is revolved by the driving clock. These clamps are, however, operated electrically as well as by hand. A pair of bell-cranks is placed at the wedge, and to one of the long arms is attached an electro-magnet, especially designed for the purpose, and capable of pulling from 1000 to 1500 pounds. To the other arm is fastened its keeper. In operation, the magnet brings the long levers of the bell-crank together with great power, and the short ends, pressing outward, force the wedge into its groove as the screw does. After the instrument is clamped, the long arms of the bell-crank are held together by a latch, so that it is not necessary to keep the current on the magnet for more than a moment. To unclamp the instrument, another pair of magnets, precisely similar to those just described, is provided, for releasing the latch. That these magnets may be easily operated, suitable switches are arranged at the eye end of the tube, within convenient reach of the astronomer, who has merely to press a key in order to operate them. If he prefers, however, the hand wheel and screw are at his service, for each method is entirely independent of the other.

After the instrument is clamped, turning either of two other hand wheels at the eye end, similar to those just referred to, and similarly placed, revolves the bronze screw of either slow motion arm in either direction, thus producing slight angular motion of the tube on the declination or polar axis.

In this instrument, however, there is still another means at command for securing slow adjustment. Especially designed slow-speed motors are so arranged that they will revolve the nut of the slow-motion arm, while the screw stands still, thus giving an independent means of obtaining precisely the same results as are secured when the screw is revolved by the hand wheel. The motor, however, has great advantage over the hand wheel, for the astronomer need only press a button, which is much easier to reach, to let subtle electricity do the rest. The press-button switches for controlling the slow motions and clamps, like those for the quick motions, are provided with springs, so that the mechanism which they operate is in use only so long as the switch is held closed.

Not a little ingenuity is displayed in bringing a cable, containing the fourteen separate wires for operating the clamps and motors, from the stationary portion of the column to the movable declination sleeve, and from the sleeve to the tube, which in turn

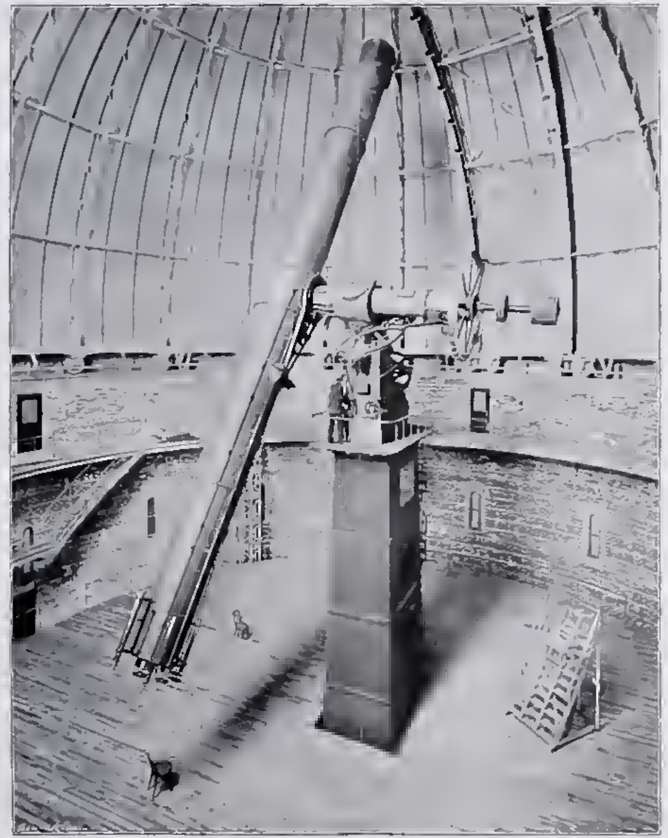

Fig. 4. 40-inch Yerkes Telescope, May, 1897.

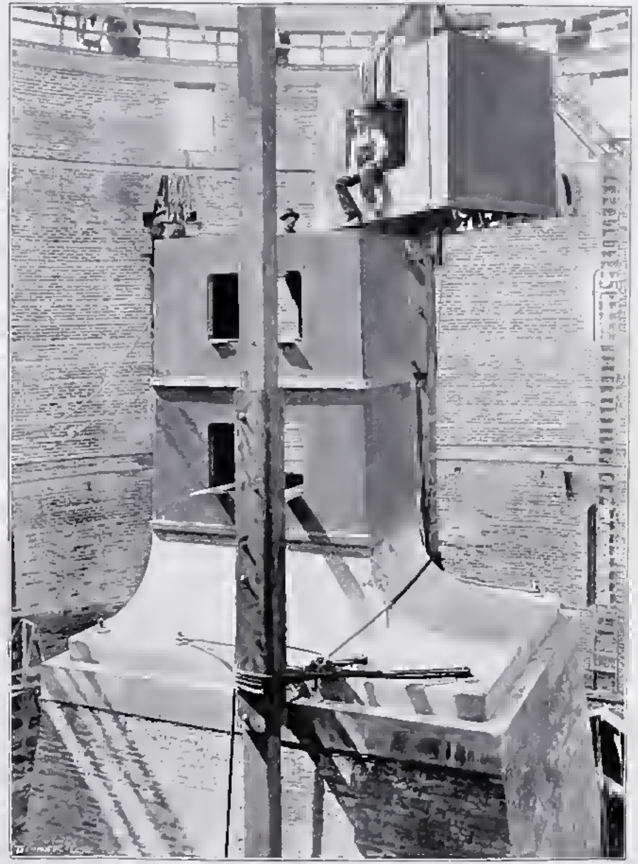

Fig. 5. Erecting the Iron Column of the Yerkes Telescope, September, 1896.

Fig. 6. Erecting the Polar Axis of the Yerkes Telescope. October, 1896.

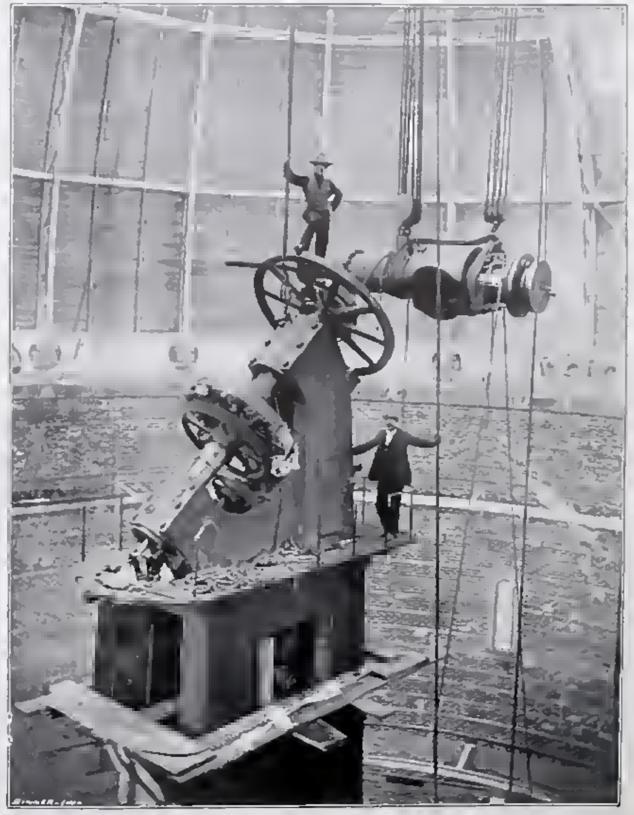

Fig. 7. Erecting the Declination Axis of the Yerkes Telescope, October, 1896.

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moves in relation to the sleeve, and from there down to the eye end of the instrument; for this must be done not only in such a way that the wires will distribute the necessary current, so hard to keep within bounds, but so that they will in no way interfere with the motion of the instrument, nor be in danger of catching and breaking asunder.

We have already spoken of the electric motors which revolve the dome and raise or lower the observing floor. These also will be controlled by switches on the elevating floor, within easy reach of the observer. When one switch is closed, the great dome turns until its mammoth shutter opening commands just that view of the heavens which the astronomer desires. When other switches are closed, the tube moves this way or that on its axes until it points approximately to the desired spot. The closing of another switch causes the floor to rise or fall until it reaches the right height for the most convenient observation. The observer touches a button at his fingers' end, and the instrument is clamped, so that the clock, from that moment, carries the tube steadily forward, keeping it upon a single point in the heavens, regardless of the motion of the earth. He touches another, and the slow motions bring the object of his search into the very center of the field of the objective.

It is partly in the successful application of electrical devices of this sort that the 40-inch telescope of the Yerkes Observatory differs mechanically from any heretofore constructed, and it is with eager interest that the face of the astronomical world is turned towards this new observatory and its corps of able astronomers; to this instrument—this princely gift to the University of Chicago—which now stands without a rival: as it were, a court of last appeal; a telescope which not only has an objective with light-gathering capacity 25 per cent. in excess of the largest hitherto made, but which is even more perfect in the simplicity of its design and the uniqueness of its equipment.

It was said of the great telescope of the Lick Observatory that the limit had been reached, that no larger instrument would be made; but, standing in the light of the accomplishment of the present, let us be profoundly grateful that it is given to man to demonstrate that the impossibilities of yesterday are the achievements of to-day, and let it be with the utmost caution that we place limitations upon the future.

The author is indebted to Prof. E. E. Barnard for the photograph from which the general view of the observatory was made, and to Prof. George E. Hale, director of the Yerkes Observatory, for enabling him to secure electrotypes from the University of Chicago Press for the other illustrations.

HYDRAULIC DREDGING: ITS ORIGIN, GROWTH AND PRESENT STATUS.*

By W. H. Smyth, M.E.

[Read before the Technical Society of the Pacific Coast, October 1, 1897.†]

"Balme made a vertical wheel, which worked between two boats, armed with six buckets, which lifted a vast deal of mud."

Probably not more than one out of the hundreds who have read this statement in Cresy's "Encyclopedia of Engineering" have given it a second thought, or seen in it more than a simple statement of a not very important historical fact. To that one, however, it was the hint, suggestion, inspiration or what not, which completed a work of years and gave to man another tool wherewith to mold the face of the earth, and to the world a new art—hydraulic dredging.

Every new art is the product of a growth and development to which the work and intelligence of many have contributed. Sometimes the development is extremely gradual, so that to no one man more than to a thousand others can credit be accorded. And again, in the life and labor of one man the scattered and disconnected influences combine with favorable conditions and bring about the same result with an appearance of suddenness. In either case the process of development is the same. To the latter of these two classes belongs the subject of this paper.

Misconception and much confusion of mind are apparent in the discussions of the subject by practical men both in and out of the courts. This is almost wholly due to misunderstanding as to what is and what is not embraced in the subject. A definition, therefore, it is hoped, will clear the way for an intelligent and connected discussion, and avoid the necessity of numerous explanations later.

The art of hydraulic dredging involves: (1) The mechanical severing of material from a water bottom; (2) the lifting of the severed material therefrom by atmospheric pressure; and (3) the transporting of it (mixed with water), by mechanical pressure, through pipes to any desired place of deposit, these three processes constituting one continuous and connected operation.

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* Copies of this paper were sent to the several parties to the hydraulic dredger litigation, with invitation to be present and discuss the paper. The illustrations are in part from photographs of well-known machines and partly from the records of the courts.

† Manuscript received Oct. 27, 1897.—Secretary, Ass'n of Eng. Socs.

To review briefly the salient points in the progress of this art is the object of this paper.

The historian, looking backward, can trace the growth of institutions and note the trend and importance of past events affecting this growth, which, to contemporaries, appear trivial and without significance. As with such institutions, so is it also with the evolution of an art.

Scattered along its pathway can always be seen hints and foreshadowings, devices frequently foolish and impracticable, as viewed in the light of later knowledge, though at times almost prophetic; others again lacking but one little ray from that light to illumine the step that separates success from failure.

The art of hydraulic dredging is no exception to this rule.

Prior to 1878 the only forms of dredgers in use for handling hard material were the dipper, the clam-shell and the endless chain bucket. These might all be classified under one head, in that their action is purely mechanical. While differing in detail of construction, they all work on substantially the same principle, viz: that of scooping the spoil from the bottom and dumping it on shore or into lighters alongside.

Though these are so well known and their names so peculiarly appropriate that a detailed description here would be out of place, yet, for continuity of the discussion, a few words of explanation will be given to each of these devices.

The dipper dredger is characterized by a huge bucket or dipper, having a capacity of from 1 to 5 cubic yards, the handle of which is a beam of wood or iron 20 to 60 feet in length, mounted and guided on a projecting arm or boom. Operating chains are provided whereby motion is given to it practically identical to that of its humble namesake, if used to scoop sand from a shallow pool and dump it into a bucket close by. To obviate the undesirable necessity of reversing a dipper of such large size to free it of its contents, the bottom is hinged and opens to discharge the spoil.

The excavator of the clam-shell dredge, in its most simple form, consists of a semi-cylindrical bucket, made in two halves, which are hinged together along the axis of the cylinder, thus forming jaws opening outward and upward. This bucket is attached to chains or poles, whereby it is lowered, with its jaws open, into the mud bottom. The closing of the jaws scoops the mud, and, when the bucket has been hoisted and swung over the lighter, opening the jaws discharges the contents thereinto.

The endless chain bucket, a more elaborate device, differs

from both the preceding, in that its operation is continuous. The main feature of its excavator is an endless traveling chain passing around a pulley or tumbler at each end bight. To this, chain scoops or buckets are attached at intervals. The chain, with its tumblers, is mounted upon a sloping frame, called a ladder, pivoted at its upper end; thus the buckets at the lower end are dipped in the mud bottom, and by the travel of the chain each bucket is successively filled, raised and discharged of its contents.

Each of these devices is, of course, mounted upon a floating barge or boat.

Dredging operations are often carried on at a distance from the shore, so that provision must be made for disposal of the excavated material. In connection with the devices just referred to, this function is usually performed by scows or lighters. In canals and similar places, where the distance to shore is not great, though too far for the unaided dredge, a flume or suspended spout has been sometimes employed.

In technical literature, extending back to the remote past, are numerous suggestions of other forms of dredging devices. Wheels of large diameter, provided with cutting and lifting devices, have received much attention, and many attempts to construct practical dredgers on this plan have been made. Perhaps the most notable of these was the Fondé and Lyons dredge, well named "Leviathan." This was built in New York about 1858 or 1859. It consisted of a wheel about 60 feet in diameter, mounted like a huge paddle wheel in a longitudinal slot amidships of a boat, and so arranged as to be raised and lowered by screws. Upon its periphery were large parallel-sided boxes for scooping the mud. This device, when put in operation, developed at least one unexpected result. In making the first cut its work was beyond criticism, but all efforts to make it take a second cut parallel to the first proved abortive. When started on a second cut the dredge would crowd over toward and across the first and attack the opposite bank, until the same influence started it back again, thus making a zigzag cut, back and forth across the first one. This difficulty appears to have proved insuperable, for nothing has since been heard of the device. Wheel dredgers have been very attractive to inventors, owing to their recognized capability for cutting and lifting spoil. The inherent difficulty of handling and managing them has, however, always proved a stumbling-block to success.

As far back as the knowledge of "suction" pumping extends, it has been known that sand and fluid mud would come up in

pumping when the suction pipe met with such material, and sand pumps, based upon this knowledge, have not infrequently been constructed.

Soon after centrifugal pumps attained commercial efficiency, their adaptability to this class of work was recognized. The condition of knowledge in this line a generation back is well illustrated in the following extract from *Engineering* (London, England, January 1, 1869):

"In a recent number we gave a description of a centrifugal "dredger now in course of construction at Messrs. Gwynne & "Co.'s works, and having been favored with a copy of the working "drawings, we are now able to lay before our readers all the "details of this interesting machine.

"In order to describe it fully, we must repeat the principle "of action of the centrifugal dredger, in the design of which "Messrs. Gwynne & Co. have been guided by the experience "obtained from the working of their well-known centrifugal "pumps. . . . In their large pumps used for draining lakes "in Holland, Denmark, etc., fish, like carp and eels, sometimes of "considerable size, have been sucked in and discharged unin-"jured. . . . Sand and mud properly mixed, with about half "the volume of water, have been also lifted, and often pumps have "been constructed solely for that purpose. . . .

"The *applicability*, therefore, of the centrifugal pump for "dredging purposes had been established beyond a doubt, and it "was necessary only to give it a form suitable for the requirements "of the case. . . . We have been informed that centrifugal "pumps have been in use for deepening the bed of the Mississippi.* "There the telescopic suction pipe of a pump, fixed on a barge, "was driven two feet into the sand, and the water, on being drawn "in and washing up the surrounding sand, formed a sort of hole. "The barge was then removed to another place and the operation "repeated."

Still earlier than this, viz: in 1856, Louis Schwartzkopff, a German, took out, in England, a patent on a device which foreshadows in a remarkable manner the modern hydraulic dredger. An inspection of his drawings renders irresistible the conviction that, had his knowledge of the conditions involved in the problem equaled his ingenuity, the art of hydraulic dredging would have entered upon its career of usefulness a quarter of a century earlier than it did. It does not appear that this device was ever put into

* The writer has been unable to find any other record of this Mississippi sand-pumping.

operation, and a careful examination of the patent shows that, without material changes, such an attempt must have proved fruitless.

There are records of many other devices which vaguely show, on the part of their originators, a more or less perfect appreciation of the availability of individual elements now employed in hydraulic dredging, but their importance in this connection does not warrant more particular consideration. For all practical purposes, the devices which have been described include everything within the state of the art bearing directly upon the subject of hydraulic dredging at the date when this method was first put into operation.

Around the Bay of San Francisco there are vast stretches of shoal, swamp and overflow land, consisting of alluvium of great depth and extraordinary fertility when reclaimed. It is not surprising, therefore, that attention was early turned to the consideration of means for the reclamation of this rich domain. The necessity for opening and deepening navigable channels in the shoal tide lands on the eastern side of the bay gave added impulse to the construction and improvement of dredging devices on this coast. Under these favorable conditions dredgers of the types described soon reached, in California, a very high, if not the highest, degree of improvement in construction and efficiency. It is important, in the present connection, to note that, though the devices for severing and lifting spoil were thus brought to a high degree of excellence, that other and almost equally important factor in dredging, *means for the transportation and disposal of the dredged material, had for some reason been neglected, and remained far behind the others in efficiency.*

This was the condition of affairs when hydraulic dredging came upon the scene.

We must now go back a generation. In 1853, at Shaw's Flat, Tuolumne county, Cal., a series of experiments were made by a young engineer to determine the capacity of flowing water to transport sand and earthy material in open conduits, and its availability in the construction of dams in mountainous districts. Ten years later the necessity of levees for the low-lying lands along the Sacramento river became a subject of pressing and daily consideration. Recalling his early investigations, he gave the subject much thought, and soon afterward took up the experiments again, "to see whether it was feasible to take material from the Sacramento river, and, with a low head of water, put it on the banks for the purpose of building levees."

In these later experiments a pipe was used; it was provided

with a low hopper for the reception of material to be transported, as in the device shown three years later in the English patent 286, of 1866, issued to James Robertson. It was found that by elevating the hopper to form a "pressure column," with a rapid stream flowing through the pipe, sand could be transported a long distance up a slight incline or for a short distance up a much steeper incline to a point considerably higher than the top of the pressure column.

In the event of these experiments proving the feasibility of this method of transportation, it was contemplated to employ it in conjunction with a clam-shell or chain bucket dredge, the aim being *to raise the transporting function to a par with the efficiency of the severing and lifting devices* of the dredgers then in use; and, further, to do this in such form that distance across water would not act as a bar to its use, as it would, for instance, with an open conduit or with a closed one dependent solely upon gravity.

In these experiments a result was observed which for a time threatened the utility of the whole scheme, and did, in fact, very materially affect the ultimate outcome. It was found that, though rapidly flowing water in a pipe constituted a transporting agent of great capacity, the outflowing stream distributed the material over an extremely large area, so that as a means for forming embankments or building levees it seemed hopelessly unavailable. To overcome this difficulty without detracting from the commercial utility of the method, numerous expedients were tried, with but meager results until it was observed that sand and water do not move in a pipe as a homogeneous fluid, and that the sand travels below the water. This suggested cutting holes in the bottom of the pipe at some distance from the end. The solid matter was thus almost perfectly separated, and the capability of the device to produce levees of excellent contour fully demonstrated. This was in 1863.

During the course of these investigations it became evident that a principle was involved which reached beyond the immediate goal of the experiments. As a transporting agency the device not only surpassed expectations, but also *far exceeded any dredger then known in capacity for supplying spoil.* Thus the dredging and transporting functions had changed places in point of comparative efficiency.

To produce a combination in which the device for excavating and raising the spoil would equal in capacity the capability of the transporting device to dispose of the material, and thus form "an ideal dredge," was a problem to which the following eight months

were devoted. Operations meanwhile were suspended on the levee proposition, pending the issue of the later and more important undertaking. Pursuing, with untiring persistency and thoroughness, every avenue which might lead to the object sought, the young engineer made himself familiar with the history and state of the art in dredging appliances. In the course of this investigation, on the 12th of July, 1864, in the Mercantile Library of San Francisco, he read the statement with which this article opens. The words, "lifted a vast deal of mud," arrested his attention. They perfectly expressed the device so earnestly sought. For the remainder of the day and far into the night a bucket-wheel which would "lift a vast deal of mud" engrossed his thoughts. Was it possible to combine, in practical form, an excavator wheel with the new transporting device, when all past experience with like excavators pointed only to failure? Before morning, however, the design for such a combination became clear. Two sketches, made early on the following day, present the result, and the memorandum thereon gives naive expression to his satisfaction thereat. This sketch, which has occupied an important place in the subsequent dredger litigation, was made upon a piece of common brown wrapping paper, and, though but rough in execution, it undoubtedly shows every essential element of the modern hydraulic dredge. One point in the memorandum, it should be noted, referred to as "this principle of inward delivery," has been a subject of much disagreement and controversy between mechanics and experts. The records show no suggestion, prior to this, of a rotary excavator in which the material, when severed, thereby passed interiorly to a suction pipe, or which had, to use the phrase hackneyed in this connection, "inward delivery to a suction pipe."

During the long period of years since 1864, hundreds, if not thousands, of models, drawings and sketches have been made by the inventor, most of which, in the natural order of things, have been lost or destroyed. More than enough remain, however, to make difficult a selection of those which most fittingly show the growth of the invention into mechanical form.

From 1868 to 1876 he was particularly active in his endeavors to get the invention into practical operation, only to meet with disappointment and delay, though many times on the verge of success.

Somewhat discouraged by lack of success in persuading practical men to put money into the enterprise, he decided to protect the invention. The records show that an application for a patent

was prepared, and also a receipt for money paid thereon, dated August 22, 1872. In December, 1876, application for patent was filed. On April, 1877, allowance was reached, which contained twenty claims. The allowance of these claims had been procured and amendments made without consultation with the inventor, and apparently without due consideration of the importance of the subject-matter. When made aware of the nature of the claims, he refused to accept or issue the patent, and permitted the application to lapse. In 1879 this application was renewed, in accordance with the provisions of the law in such cases. This renewal dragged along in the Patent Office until June, 1882, when the power of attorney was revoked by the following characteristic letter:

613 MISSION STREET,
SAN FRANCISCO, June 13, 1882.

To the Commissioner of Patents, Washington, D. C.:

SIR: Unable to fee attorneys to prosecute my cases at the Patent Office, they hang fire while I grow gray. It becomes necessary for me to do the best I can with them myself. The power of attorney heretofore granted by me to Messrs. ———, of San Francisco, and Messrs. ———, of Washington, D. C., is hereby revoked in the case of the renewed application for improvements in dredging machines. Ignorant of the changes that may have been made in the specification or drawings, I enclose $5 for contents of the file wrapper. I cannot give the number.

Respectfully,
A. B. BOWERS.

From this time on he prosecuted his own case, with the result that the one application, with its twenty claims, was divided into eleven divisional applications, all of which were allowed in due course, and issued with an aggregate of 363 claims. He has since taken out other patents and has other applications pending.

Prior to this, however, in 1878, A. E. Davis, president of the South Pacific Coast Railroad, was induced to advance money for the construction of an experimental machine under the supervision of the inventor. This dredge was built entirely from second-hand material picked up here and there. The dredge boat was an old mud scow, and upon it was mounted a 40-horse-power engine, connected to drive a centrifugal pump having a runner 27 inches in diameter. The suction pipe, with its rotary excavator, was rigged outboard along one side, and the discharge pipe consisted of a number of lengths of 14-inch pipes, on floats, connected into a continuous flexible pipe by short lengths of leather hose and 200 feet of canvas hose, reaching to an enclosure on shore.

Notwithstanding these disadvantages, and the fact that the

canvas hose frequently burst, the device handled a large amount of thick mud. The operation of this machine was witnessed by a number of prominent persons and government officials, who have testified to these facts. One of the spectators was so impressed that, in a letter written at the time to an Eastern correspondent and referring to the machine, he said: "It can dig mud faster than any three machines I ever saw."

This was the *first* application of the modern art of hydraulic dredging.

Thus, after fourteen years, came the fruition of long endeavor. A device had been achieved which not only severed and "lifted a vast deal of mud," but also deposited it on shore in one continuous operation. The work of the inventor was done. His "faith in the combination of elements," shown in 1864, was demonstrated to have been well founded. The further declaration of intention "to patent and profit from it" still remained to be accomplished.

Hydraulic dredging now began to be appreciated as an important factor in reclamation and similar works. The time had arrived when practical men needed no persuading to invest money. Results—the sum of all good to the practical mind—were now in abundant evidence, and those of practical mind were not slow to take advantage. A couple of years previously Col. Allexey W. von Schmidt had constructed, for the purpose of levee building on the Sacramento river, a large sand pump, mounted upon a barge and having a suspended pipe to convey the sand ashore. It was also provided with a propeller-shaped rotary implement in the flared mouth of the suction pipe. This was afterward remodeled by the Golden State and Miners Iron Works by incorporating the rotary cutter with inward delivery, the floating discharge pipe and other hydraulic dredger devices. This remodeled machine became known as the Williams & Bixler "Atlas" dredge.

Improvers, and "inventors" too, found a new field for the exercise of their skill, and took up their task in the evolutionary process. Pumps for hydraulic dredgers, rotary excavators with inward delivery, floating pipes with flexible joints—all these and many other details became the subjects of numerous patented inventions.

It was not long, therefore, before hydraulic dredges were at work, each differing slightly from the others and from the designs of the original inventor, though incorporating, in different forms, the essential characteristics disclosed by him.

In 1883 Von Schmidt built another machine to execute some extensive dredging contracts. He was, in fact, the first to put this new method to the test of commercial competition with the older form of dredges. Profiting by his experience with the earlier machine, he made changes, which he covered by patents No. 277,-177, May 8, 1883, and No. 300,333, dated June 10, 1884. With this machine he used a floating and jointed discharge pipe. The excavator was a rotary one with inward delivery. The San Francisco Bridge Company also built dredgers upon the new plan, and with them "lifted a vast deal of mud." Others, also, both in California and elsewhere, showed their awakened appreciation of this method by building and using hydraulic dredgers.

Now commenced the era of litigation, through which every new device of value must pass.

Owing to the saving effected by the hydraulic dredger, the great cost of each machine and the magnitude of the undertakings in which they are employed, the dredger litigation has been stubbornly, persistently and most ably contested, and has taken a place, both in importance and interest, in the front rank of patent causes.

The amount of testimony taken has extended into thousands of printed pages; wagon loads of exhibits have been employed in illustration; the libraries and patent archives of the world have been ransacked during the past decade in this war of interests.

In 1888 suit for infringement was commenced against A. W. Von Schmidt by Alphonso B. Bowers. An interlocutory decree was rendered in the Circuit Court by Judge McKenna (now Attorney-General of the United States). This decree was affirmed on appeal by the United States Circuit Court of Appeals, January 4, 1897. As a last resort, an endeavor was made to reopen the case by application to the United States Supreme Court for a writ of certiorari on certain points of patent practice claimed to be unadjudicated, but without avail. The writ was refused, and this case was thus settled beyond appeal.

A few months earlier, in 1888, suit was commenced against Williams & Bixler and others, having reference to Von Schmidt's first machine as remodeled. This, after the testimony had all been taken, was settled by compromise, payment of damages and entry of interlocutory and final decrees in favor of Bowers.

Suit was commenced against the San Francisco Bridge Company, March, 1893. In this case testimony is all in, and it has been argued and submitted to Judge W. W. Morrow, of the United States Circuit Court, for decision.

Bowers *vs.* Pacific Coast Dredging and Reclamation Com-

pany and John Hackett was commenced September, 1894. Preliminary injunction was granted in this case by Judge W. W. Morrow.

Bowers *vs.* Alexander McNee and others.

This case was settled by compromise, entry of final decree in favor of complainant and payment of damages.

Bowers *vs.* New York Dredging Company and San Francisco Bridge Company. This suit was commenced at the city of Tacoma, Wash. A preliminary injunction was granted therein by Judge C. H. Hanford, United States District Judge.

Other suits are pending and to be commenced.

The position taken by Bowers in these suits is that he was the first to devise:

(*a*) A rotary excavator with inward delivery through itself to a suction pipe.

(*b*) A floating discharge pipe which would transport the spoils from a dredger over the water and deliver them to any desired point on shore.

(*c*) A machine to dredge on a circular arc while the boat oscillates on a self-contained pivot and acts as a rigid radius holding the cutter to its work.

(*d*) A machine to make an arc-shaped cut with an excavator while the boat is oscillating on a self-contained pivot, and then to move the machine ahead and make a second similar arc-shaped cut, and so on thereafter continuously, until a clean, smooth bottom is dredged.

(*e*) A machine to cut and sever material in place at the bottom of a waterway with a rotary excavator having side feed and inward delivery, carry the material inboard by suction and then force it through a flexible pipe, floating on or submerged under the water, to any desired place in the water or on shore, to be used for filling purposes, if desired.

In the Von Schmidt case the defendant first denied each and all of these claims, and contended that he (Von Schmidt) was the first inventor of the hydraulic dredge and the first to put it into practical use; that the Davis dredge of 1878 was impracticable, useless and inoperative; but later he introduced patents antedating his own invention, and questioned the validity of Bowers' patents on the grounds of anticipation, abandonment and various other grounds relating to acts both of the inventor and of the Patent Office. He questioned the authenticity of the drawings of 1864, claiming them to have been made twenty years later and antedated. He denied that it required the exercise of "invention"

to produce the devices of Bowers from the prior state of the art. He contended that Bowers' devices never did, in fact, work on the "hydraulic principle," as that term is applied to modern dredgers, but that they were constructed upon the principle illustrated in the early experiments with the "pressure column." He contended that the patents sued on should be construed literally and restricted to the exact construction shown and described, and that "inward delivery" should be construed to mean mechanical transportation of the severed material from the point of severance to the entrance of the suction pipe, unaided by atmospheric pressure.

In the San Francisco Bridge Company case, now awaiting decision, practically the same defences were made as in the Von Schmidt case, except that the authenticity of the drawings of 1864 was not called in question, and more emphasis was placed upon the "pressure column" theory in an endeavor to prove that "the law of the machine" in question is different from that of the patent; in other words, that the fundamental idea upon which each machine is based is different, and consequently the machines themselves must be different.

Much emphasis was also placed upon the Schwartzkopff patent, introduced into this case as new evidence.

The decree in the Von Schmidt case is very broad, and the decision of the Circuit Court of Appeals is still more clear and comprehensive. Only a few short extracts can, however, be given.

After analyzing the prior state of the art, the decision goes on to say: "But prior to the complainant coming into the field there was no machine, by whatever name known, that would, by the simultaneous and continuous co-operation of its various elements, cut and remove hard material from a waterway, and itself transport the same to any desired distance and place." Referring to the drawings of July, 1864, the decision continues: "Counsel for the appellant assert in argument that this date is false; that the drawing was actually made in 1884 and antedated twenty years. . . . There is nothing in the circumstance relied upon by the appellant to cast any doubt upon the testimony of the complainant in respect to the drawings, especially as there is much corroborative testimony. . . . We are satisfied from the evidence that they, together with the memorandum appearing upon them, were made at the time they respectively bear date. . . . They show not only an altogether new combination of elements for the transportation of spoils, but also something radically new in rotary excavators, namely: a rotary excavator with inward delivery

through itself, in combination with a suction pipe. They show a dredge-boat having two self-contained pivots or centers of oscillation for swinging of the boat while at work; a flexible joint near the pivots; a discharge pipe consisting of an inner flexible oscillating section composed of a series of sections flexibly joined together and supported by floats; and an outer rigid non-oscillating section, a suction pipe, a rotary excavator having inward delivery, the arc-shaped cuts of the excavator made by the dredge while swinging from side to side on the pivot, and devices for working with a side feed." Referring to the delays in connection with the patents, the decree continues: "It is enough to say that, so far from showing any intentional abandonment, they show the most persistent and continuous effort on his part against very adverse circumstances to perfect and avail himself of its benefits."

Referring to the experimental machine, the decision says: "The fact, if it be a fact, that the first machine built by complainant, called in the records the Davis machine, was not successful in its operations, is unimportant. . . . It would be certainly a novel doctrine to deny to an inventor the fruits of a broad invention because the machine which first embodied it was rudimentary in character and failed to do as good work as improved machines made subsequently. None of the great inventors could survive such a test. . . . He is, therefore, justly entitled to be regarded as standing at the head of the art of hydraulic dredging."

This story of the growth of a machine can hardly be other than what it is intended to be—a prosaic statement of facts and dates from sworn testimony of court records and personal observation. A few readers, here and there, can, like the writer, fill in the blank of years so lightly passed by in narration. To these this story will present another and entirely different aspect, one which thrills with human feeling and sympathy; a story of trial, disappointment and hope deferred; of ill-health and reproach; of high hopes and ambitions; of youth and manhood worn away as slowly, but surely, as dropping water wears stone by the passing days of passing years. These will know that progress as well as religion demands its martyrs, and that success, so dazzling to the beholder, is but a lightning flash on a summer evening, incapable of dissipating the chill of a life's journey in the valley of shadows.

DISCUSSION.

Prof. Soule.—I would like to ask Mr. Bowers about the dredger that was built and attempted to be operated in Oakland. I think it was about 1870 or 1874. I think a man by the name

of Ball was the inventor. As I understand, it did not prove successful.

Mr. A. B. Bowers.—I am thoroughly familiar with the dredge referred to. It was not a suction dredge, but had an endless chain of buckets, from which the spoil was dumped into a chute and discharged into a scow alongside. Later on, about 1880, he got up a dredge for A. E. Davis, in which the chain of buckets dumped into an elevated hopper, into which a stream of water was pumped, and the spoil and water descended by gravity through an inclined pipe into and through a short length of horizontal pipe. The mud, mixed with water, was carried through a short length of discharge pipe with considerable facility, in spite of its greater specific gravity, but when the inventor came to add any considerable length to his discharge pipe he met with difficulty in transporting the material. He was at work at Alameda Point for several weeks, but did not succeed in satisfying Mr. Davis, the owner of the machine, who soon after dismantled it.

Mr. Grunsky.—A dredging machine, possibly the same that has been referred to as the "Williams & Bixler," was at work in 1878 in the San Joaquin river. The material handled was principally sand. It was pumped up from the bottom of the river and deposited on shore through a suspended pipe. I noticed on the dredge an assortment of variously-shaped hoods that had been tried for the purpose of compelling the water—in flowing around the edges of the hood-shaped pipe-end—to take up the sand. I have only an imperfect recollection of the machine, which I did not carefully examine. Perhaps Mr. Bowers can give some additional information about this machine. I believe it was called the "Von Schmidt" at that time, but from the description given in the paper this evening I infer it might have been the "Williams & Bixler."

Mr. Bowers.—That was the first Von Schmidt machine. It was built for Williams & Bixler in the fall or winter of 1876. The suction pipe had an outer vertical telescoping section provided with a flared mouth or hood, about eight feet in diameter, within which was a rotary propeller-shaped agitator designed for an excavator. The diameter of this agitator was considerably less than that of the hood, but it depended some three or four inches below the hood. This agitator was unable to cut hard material, but if it had succeeded in boring a hole of its own diameter, or a little larger, by lowering it and the hood, it could go no deeper than its projection below the hood, because the greater diameter of the hood would cause it to rest on the uncut material around

the hole made by the agitator or excavator, and this propeller-shaped device projected so slightly below the hood that it would not have been practicable to work it with a side feed or swing, even had it otherwise been capable of so working, because, in order to do this, the bottom would have had to be perfectly level, parallel with the surface of the water. If the propeller was swung sidewise it would take off nothing but a thin shaving from the bottom. And, even if the bottom had been perfectly smooth and level, the propeller blades had not sufficient excavating capacity to make the device practical, while in soft material and loose sand it was discarded as useless.

The owners of that machine, finding that it would not answer their purposes except for pumping sand, had it remodeled, as stated by Mr. Smyth, into what was known as the first "Atlas" dredge, a prototype of the dredge now used by the San Francisco Bridge Company and the New York Dredging Company. It is almost exactly the same, though a few small changes have been made in the details. This was the first dredge of the "Atlas" type ever constructed, and was built at the Golden State and Miners Iron Works.

Prof. Soule.—I believe that hydraulic dredging has recently been carried on upon a very large scale on the Mississippi river, in relation to levee work there.

Mr. Grunsky.—I think chiefly in regard to deepening the channel and cutting through bars. The object is to keep open a narrow, deep channel during the low-water season.

Prof. Soule.—I have been told that a great deal of matter is handled, and that the power of the pumping engines has been greatly increased, so as to throw the water through the pipe at a much higher velocity than formerly, and that by doing this a much larger percentage of material is secured with the water—I think as high as 50, or even a greater percentage.

Mr. Smyth.—In some hydraulic dredging operations samples of the discharge ranged as high as 70 per cent. in solid material. It is doubtless desirable to have a high velocity in the carrying stream. The higher the velocity the greater, of course, is its burden-carrying capacity; but as water, traveling six inches per second, will move sand, and as the speed of flow, in ordinary dredging operations, is about fifteen feet per second, it would seem that this velocity would carry about all that could be excavated. The difficulty met with usually lies, I think, in the construction of the excavator, and particularly in the fact that the suction opening is not brought sufficiently close to the bank.

The suction pipe is frequently placed centrally in the excavator, and the material has, consequently, to be raised through considerable distance. In this form of construction the velocity of the stream, at the circumference of the excavator, in the bank where the cutting is done, is very much less than at the mouth of the suction pipe. This matter does not appear to have received the consideration due to its importance. In the San Francisco Bridge Company's construction something has been done in this direction by entering the suction pipe in the lower segment of the excavator and opening it downward, thus bringing its mouth nearer the point of excavating operations, and the excavated material more nearly within the influence of the inrushing current at its point of greatest intensity.

Mr. Bowers.—I have given considerable thought to the construction of excavators for hydraulic dredgers. I have designed many different forms, and have carefully noted the performance of others. In nearly all excavators having an inward delivery spoil finds its way to the mouth of the suction pipe with sufficient facility, except in very hard or in very sticky material, for each of which special and very different provision should be made. There are advantages and disadvantages with both concentric and eccentric suction pipes, considered in relation to the excavator, but in most cases either, when properly handled, is sufficiently efficient to furnish the pump with all the spoil it can force through the discharge pipe.

Mr. Grunsky.—I might add that the dredgers used on the Mississippi are of very large capacity. The largest have six suction pipes supplying two large centrifugal pumps. Three suction pipes deliver into each pump. These pumps send the material and the water through a discharge pipe that trails behind. The material is generally sent down stream 2000 feet or more and deposited in some deeper spot in the river channel. The material is not used for building levees. The channels cut through bars are only intended to benefit low-water navigation temporarily. I am told that the latest experiments have been to determine the efficiency of water jets used as a substitute for the rotary cutter in severing material. I do not know what the results have been.

Mr. Smyth.—In my previous remarks I suggested that lack of efficiency was not due to lack of speed of the current. This is borne out by the fact that in many excavators, and notably in those of the San Francisco Bridge Company, they bring up large boulders; in fact, I saw in court one day a cannon ball, eight inches in diameter, which had been raised by the suction pipe. Mr.

Bowers' dredgers have raised stones of that size. It is not the speed of the water that is deficient. That ordinarily employed is sufficient to carry the material usually dredged.

Mr. Henny.—I would ask the author of the paper if he can give us some information upon the comparative cost of dredging with clam-shell dredges, with endless chain buckets and with this new method of dredging. I realize the fact that the cost is a very variable quantity, and I have in mind some instances where the different methods of dredging have been used for the same piece of work.

Mr. Smyth.—Mr. Bowers could give fuller and more accurate information, his opportunities of making the comparison desired having been much greater than mine.

Mr. Bowers.—There are circumstances under which dredging can be better done with an old Osgood scoop than with any other machine. Work of that character, in very hard material, will cost, with the scoop, from 30 cents to $1.50 a yard. Such material, under favorable conditions, can be handled with a hydraulic dredge for from 30 to 60 cents, if the discharge pipe is short and the lift is low. All of these things have to be taken into consideration. You can handle a very large percentage of sand or gravel through a short pipe with a low lift, and do it without great expense other than that of the wear and tear of the machine, which is excessive in sharp gravel.

There is other material to be taken up and deposited 50 to 75 feet alongside from where it is found, and such can be handled more cheaply with a long-boom clam-shell than with any other device that has ever been employed. This machine is particularly well adapted to the building of levees, where the material is within reach of the boom, and where the boom can carry it to its proper place in the levee. Soft, semi-liquid material cannot be taken up with any considerable advantage by either of these machines, or by the endless chain bucket. The passage of loaded buckets through the water will wash out such material, and the jaws of the clam-shell are seldom close fitting, but are usually separated sufficiently to allow sand and soft and semi-liquid material to escape in considerable quantities. A very considerable percentage of such material is lost by leakage, as well as by being washed out, as it is raised through the water. For this class of work hydraulic dredgers are vastly preferable under suitable conditions, as well as for the excavation and transportation of most material where the point of discharge is not too distant and at too great an elevation. In such cases hydraulic dredgers are efficient and econom-

ical. In the handling of sedimentary deposits, and even clay and compact sand, the cost, with the hydraulic process, is probably less than one-half the cost by any other method where the material has to be put on shore within a reasonable distance, but beyond the reach of the ordinary machines.

The last contract given by the United States Government for dredging with a clam-shell between the Oakland jetties was taken by Mr. John Hackett, and the price he received for it was 34 cents a cubic yard. He was required to take the material out of the channel and deposit it on shore. He put it into scows and towed it to a wharf near the mouth of the Oakland creek, and there dumped it alongside the wharf. On the wharf he had another clam-shell dredge that took the material up again and put it into dirt cars furnished by the Southern Pacific Railroad Company, for which he was paid 4 cents a cubic yard, if my memory serves me rightly. The superintendent of the Southern Pacific Railroad Company told me that it cost the company 12 cents a cubic yard to transport the material, shovel it off the cars and spread it over the ground. They had to use shovels in unloading, because the mud was very sticky—a sort of clay. They first laid a temporary track and shoveled off the mud on each side, then took up the track and put it in another place close by, parallel with the first, and so continued that process, though after a time they discharged the material only on one side, and then moved the track back as the place was filled, in order to make clean work as they went along. This would be, then, 34 cents for dredging and towing, 4 cents for taking the material up again and putting it into cars and 12 cents for transporting on cars and unloading, making a total of 50 cents per cubic yard for dredging the material in that way and transmitting and spreading it over the land. Hydraulic dredge contractors now think that if they get a large contract for doing such work at 15 cents a cubic yard they are doing fairly well, if the material is to be delivered at a low elevation through a short discharge pipe, with all other conditions favorable. The hydraulic dredge is a special tool for special work, and, in its own sphere, is without a rival. Having patented my dredge mainly for my own protection and use as a contractor, and for the protection of my licensees, it is obviously unwise for me to chant its praises too loudly or to set the cost of work at too low a figure.

The "Beta," used on the Mississippi river for cutting through sand bars, has six suction pipes and six cutters on one hull. It is equivalent to six dredgers in one, and when one is laid up for

repairs the whole plant is idle. It has been at work for several months, with a very heavy percentage of lost time. I am coming very near criticising it, which I do not now wish to do. I will say, however, that it does not handle six times as much material as has been handled by a single cutter, though the quantity is very large while actually working, and all the more so from the fact that it is lifted but slightly *above* the surface and is discharged *at* the surface of the water. The results obtained from the use of this dredge have not been such as to encourage its duplication, and others of different types have been built instead. If the discharge pipe is long and the end of the pipe is considerably raised, the amount of material that can be discharged diminishes very rapidly with the elevation; but if the mouth of the discharge pipe can be kept low, a very heavy percentage of earthen material can be delivered continuously. If the discharge pipe is not too long, a heavy percentage can be delivered at a fair elevation; but with a pipe that is a mile or a mile and a half long, and with a heavy elevation at the mouth, the amount that can be delivered dwindles very rapidly with the increase of elevation.

Prof. Soule.—In what order would you place the different soils or material that can be removed by a hydraulic dredger alone, leaving out the rocks and heavy boulder material?

Mr. Bowers.—I surmise that Professor Soule, the head of the College of Engineering of the University of California, could elucidate these questions, much to our edification. From my practical experience, however, I may state that silt and semi-liquid material require but little power to sever them from the mud bottom, and can be moved very cheaply and more rapidly and economically than any other. This was the character of the spoil handled by these machines on the Drainage Canal at Chicago, where, at times, there were moved, with a single hydraulic dredge, 10,000 or 12,000 cubic yards per day of such material. The dredgers used were of simple construction—almost make-shifts—for the sake of getting up as cheap an apparatus as possible, and it is astonishing that such results were obtained from inefficient machines. This was owing to the extreme softness and liquidity of the spoil.

Taking this material with constantly increasing hardness—such as is found in sedimentary deposits, up to pure clay (for a great deal of this semi-liquid material may solidify and form clay, in the course of time)—the expense constantly increases with the increasing hardness of the material. But hard clay is a better material to handle, if it is to be transported a long distance, than

even loose sand, for the friction of sand in long pipes is excessive. When you undertake to carry sand more than half or three-quarter of a mile the friction is so great and the tendency of the sand to deposit in the pipes is such that one is obliged frequently to cease excavating and wash out the sand by pumping clear water alone. This is the case with all kinds of sand if you attempt to discharge them through too long a pipe. Coarse gravel and cobblestones, owing to their weight and the centrifugal force of the pump, rapidly cut out the shell of the pump and also the pipes through which they pass.

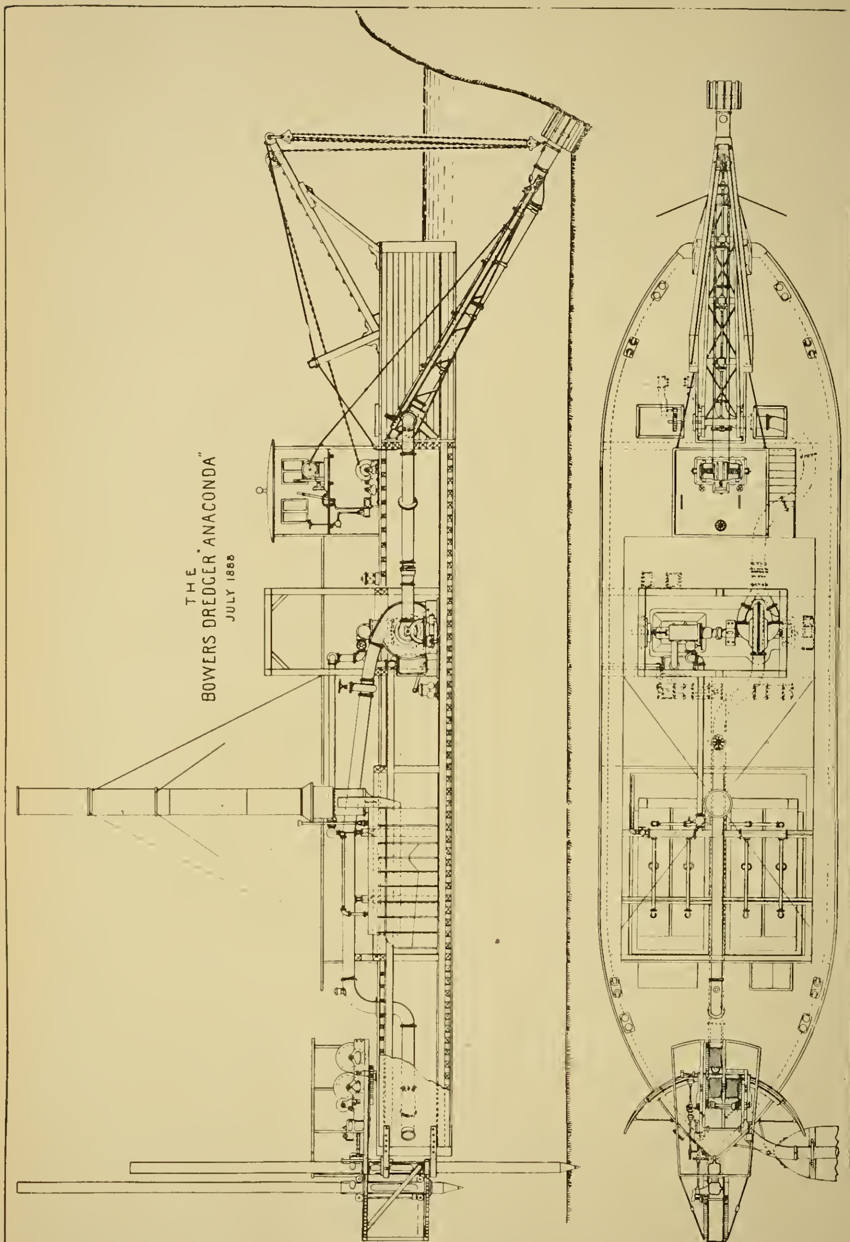
The Bowers dredge "Python," at Tacoma, took up coarse gravel, from the size of a pea up to 2 inches in diameter, with an occasional boulder as large as a man's head. This material was elevated about 30 feet and discharged through 1000 feet of pipe. But the company did not make money on the contract.

PROF. SOULE.—The gentleman who gave me the information about dredging in the Mississippi river said that one great necessity for the high velocity was to prevent the sand from settling and trailing along the bottom of the pipe.

MR. GRUNSKY.—Can any one tell me what the velocities in the delivery pipes of the Mississippi dredgers are? It attracted my attention as being in excess of that customary on this coast.

MR. BOWERS.—The flow of material in the discharge pipe of the Von Schmidt dredge, when I tested it, was about 11 feet per second. In my dredger it has run from 15 to 20 feet. The velocity in the San Francisco Bridge Company's discharge pipe is about 15 feet. It varies above and below. At the time I was on the Mississippi I witnessed some experiments with the "Beta." The velocity of the discharge was not tested at that time, but I thought, from the appearance at the end of the pipe, that it was not high. It did not seem so high as the speed I have given for the machines on this coast. This was prior to the official tests, and the speed may now be greater. It has been found, however, that a rapid stream in the discharge pipe is more advantageous, when handling sand or gravel, than a slow speed, but in handling sedimentary matter or semi-liquid, clayey or slippery material it is not so important, if only the pressure from the pump is sufficient to force the material through the pipe, even if the pipe is almost full of it.

MR. VISCHER.—I feel as though it was almost an imposition to ask Mr. Bowers for so much information, after what he has said, but as we know he has all these things at his fingers' ends, I would ask him to give us a few figures as to the size of his dredgers, and how much they handle.


THE
BOWERS DREDGER "ANACONDA"
JULY 1888

Mr. Bowers.—The first dredge that I built, after the experimental apparatus which has been referred to this evening, was the "Anaconda." That was put into operation at Glorietta Bay, a bight in the Bay of San Diego. The material there was very hard, compact sand. The dredge handled, in one run of 5 hours and 20 minutes, something over 3000 cubic yards. That was the first work of the first complete dredge that I built. It was a dredge of about 175 horse-power on the pump. That same dredge, after being taken to Tacoma, on Puget Sound, handled 165,000 cubic yards in 20 days, running continuously. The material was a sedimentary deposit, composed partly of sand and partly of clay. That, I believe, is the best record ever made. No other hydraulic dredge, with a single cutter and with the same power, has come up to this.

I constructed, for the Bowers Dredging Company, a second dredge of some 400 horse-power, and that is the one that handled the gravel and cobblestones to which I have just referred. It has not yet had an opportunity of showing what it would do under favorable circumstances. The dredgers on the Chicago Drainage Canal made no such continuous record as the "Anaconda," even in the semi-liquid material which they handled there, but for short spurts of one or two days they exceeded the average output of the "Anaconda" for these 20 days of which I have spoken. I think that the highest record they made at Chicago was a little over 100,000 cubic yards in a single month. I have the figures somewhere, but my recollection is that it was about that. It may, perhaps, have been a little higher, I am not quite sure.

The Von Schmidt dredgers at Washington, D. C., at work on the Potomac Flats, handled, in soft mud, something over 100,000 cubic yards a month. At one time they were working in sand and discharging a mixture of gravel and boulders through 1400 to 1700 feet of pipe. In this material they moved from 700 to 1200 cubic yards per day. It was frequently necessary, during the day, to raise the cutter and wash out the discharge pipe by pumping clear water. It would sometimes take two hours to clear the pipe of cobblestones, which, in passing through it, would frequently make a racket similar to that of a passing train of cars.

Mr. G. W. Dickie.—I had some experience in dredging machines as far back as 1860 and up to 1869, in connection with dredgers built by Siemens, on the Clyde. These, as you know, were the standard type of chain bucket dredgers. I am not sure whether any of the suction types of dredging machines, on a general proposition, will equal the old chain bucket dredger. There

are places where the pump dredger will do better, and certain kinds of material which it will lift and deposit cheaper, if the distance is not too great. I have in mind a dredger that was used by a railway company in England for years, and it never was laid up but a day or two at a time for repairs. It would dredge 3000 tons of material a day, mostly of stiff clay—so stiff that when it fell out of the bucket it would keep its shape. A good deal of it was moved about two miles, and the average cost was a little less than 3 pence, or 6 cents, per cubic yard. I have not heard to-night that any dredging has been done here as cheaply as that, even in easily handled material.

When we were preparing for the dry dock at the Union Iron Works the San Francisco Bridge Company had the contract for dredging. If I remember correctly, we paid them 15 cents a cubic yard. As a matter of curiosity, I kept the time of all the hands employed, the amount of coal burned and of other supplies, as near as I could, and the actual cost was between 9 and 10 cents a cubic yard. This shows that the method of dredging was not very cheap. Sometimes the amount of material, as compared with the amount of water pumped, was not very great; at other times it was up to, I should say, 60 per cent., and again it went down, probably to not over 20 per cent., and especially when the machine was taking the material below 30 feet and the ground got a little hard.

A large proportion of the dredging that will have to be done in the harbors of this country, I think, will follow the course that has been pursued in Europe; that is, to carry the material a long way. Here we deposit the material a few hundred yards from the water front, and it is not long before it comes back again. Where it is not convenient to deposit on shore, the material should be carried out and dumped beyond the ocean bar.

The pump dredger will have quite a field of operation under circumstances which favor that kind of dredging, but I am sure that a very large proportion of dredging will not admit of it, simply for want of a convenient place to put the material. It can be used only where the material can be deposited within certain distances from the excavation.

R. H. Postlethwaite.—I came here recently from New Zealand, where a great deal of dredging for gold has been done. It commenced thirty-odd years ago. It started with the old spoon dredge, which now has developed into the dipper dredge. It was originally worked by hand power, after which a current wheel was used, having continuous buckets, similar to those used now;

but this could be used only for dredging in the current of the river, and could not touch the banks, where there is a large quantity of good gold-bearing dirt. Therefore, this style of dredger had a very limited field of operation. After that came the bucket dredge, with an engine on board, run by steam, so that it might work anywhere. I think we have over 100 of these dredgers running in New Zealand.

To handle dirt for our purposes successfully and cheaply, we must have a machine that will work continuously. Especially in the saving of gold do we want a regular, continuous stream. The dredgers we are using will not only lift heavy material like gravel, but also stones and boulders, from 200 pounds to a ton in weight. I think you will find a very large field for dredging in this state when I tell you that for years in New Zealand we have operated dredges in heavy material, lifting it from 45 to 50 feet above the surface of the water. Lifting it from 20 to 30 feet has cost less than 5 cents a cubic yard. We reckon there that anything over 3 cents a cubic yard will pay expenses, and there are dozens of dredgers now which are working dirt that is not paying more than that, while those averaging 5 cents a cubic yard are paying handsomely. In removing sand we might be able to use the suction dredge more successfully. Every dredge must be built to suit the conditions in which it is to be used.

BRADLEY & POATES, ENGR'S N.Y

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PIPE LINE NO. 2 AND THE LANDS IRRIGATED UNDER IT AT CORONA, RIVERSIDE CO., CAL.

BY H. CLAY KELLOGG, MEMBER OF THE TECHNICAL SOCIETY OF THE PACIFIC COAST.

[Read before the Society, November 5, 1897.*]

CORONA, formerly known as South Riverside Colony, is situated on a mesa about three miles in width and six miles in length, on the northeastern slope of the Santa Ana Mountains, with a fall of 150 feet to the mile. The colony was laid out in 1886–7, and the first pipe line was completed in July, 1887. To-day the town and colony has a population of about 2000 inhabitants, and there are 7000 acres planted to orchards, mostly oranges and lemons.

The water supply, which is taken from the Temescal Cañon, has for the most part been developed, as there were only about fifty miners inches in sight in the beginning. These developments have been made by running submerged drains, building reservoirs and boring artesian wells. Lake Elsinore has also been secured as a reserve supply.

The increased demand for land caused investigations to be made looking to the construction of a higher pipe line to irrigate the choice lands above the line already built. This led to the construction of pipe line No. 2, the subject of this article. This line has a capacity of 400 inches, and is 150 feet in elevation above pipe line No. 1, taking in an additional area of 2000 acres.

* Manuscript received November 15, 1897.—Secretary, Ass'n of Eng. Socs.

Fig. 1. Plan of South Riverside Colony.

SOURCE OF SUPPLY.

Pipe line No. 2 is supplied by artesian wells and by a mountain stream, known as Cold Water Cañon. The supply from this stream is about 125 inches in winter and 25 inches in summer, leaving the major portion to be supplied by the wells. These wells are situated in a basin at the mouth of Cold Water Cañon. This basin is caused by a dike of fire clay which runs almost parallel to the mountain range, course N., 58° W. I regard this dike as the most important natural feature in our water supply. I have traced it for about 15 miles by the outcroppings, where large washes from the mountains intersect it, and by springs which appear all along the line. In the driest season of the year the mountain gorges are dry, except where they intersect this dike, and the peculiar feature of this is that living springs are found only along this dike. This is forcibly illustrated by a spring on top of the mountain, at the northwest end, where the dike intersects it. My theory is that the subterranean flow from the northeastern slope of the Santa Ana or Temescal range is intercepted by this dike, and that at the basin mentioned, where the artesian wells are located, the dike is farther from the mountains, making this the largest part of the subterranean reservoir. It is also opposite the highest peaks of the range, which are drained by Cold Water Cañon. I have no maps that definitely give the area of the watershed. The elevation of the highest peak is 5730 feet, and the elevation at the wells about 1100 feet.

The wells are 13 in number, and vary from 130 to 260 feet in depth, the best flows being obtained at 130 and 165 feet in depth. These wells, if capped during the winter months, will supply about 300 inches of water, and they have thus far been adequate to the demand.

PIPE LINE NO. 2.

The total length of the line is 30,093 feet, from the wells to the intersection of the lands that are irrigated. It is located over the most irregular and broken country I have seen where water has been conducted, lying parallel to a precipitous mountain and intercepting the mountain washes at right angles. In locating the line, two objects had to be kept in view, namely: to secure economy of construction, and to take in all the land possible. There were four heavy ridges to cross, and, to avoid long tunnels, a slight detour was made and more pressure pipe used. The pressure pipe was found to be cheaper, and it did not materially alter the elevation of the grade line at the terminus. Having our

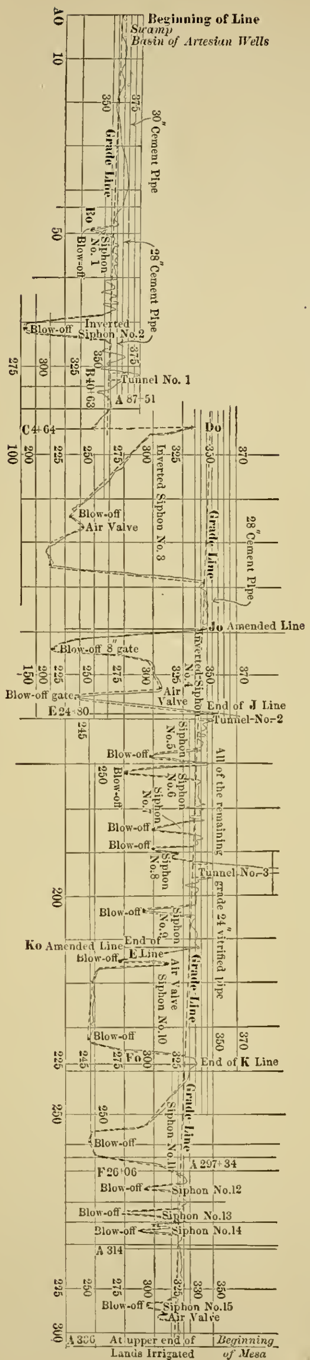

FIG. 2. PROFILE OF PIPE LINE NO. 2.

capacity fixed at 400 miner's inches, I established the hydraulic grade at 4 feet to the mile for 28-inch pipe and 7 feet to the mile for 24-inch vitrified pipe and for all 24-inch steel pipe used in inverted siphons. In the construction we put in 30-inch pipe for the first 4437 feet on a grade of 3.2 feet to the mile, 5267 feet of 28-inch pipe on a grade of 4 feet to the mile, 6237 feet of 24-inch vitrified pipe on a grade of 7 feet to the mile, and 14,125.1 feet of 24-inch double-riveted steel pipe, which was distributed throughout the line in 15 inverted siphons across the canons and washes.

CEMENT PIPE.

The cement pipe was made of three and one-half parts of clean, sharp bar sand to one of cement, and the mortar used for laying was made of two parts fine, sharp sand to one of cement. The pipe was made within a mile of the line, in Temescal creek, where the very best quality of sand and gravel can be found in large quantities. The vitrified pipe was made at the Pacific Clay Manufacturing Company's Works, which are located at Corona. The pipe used was a good quality of salt-glazed pipe.

DITCH.

The ditch to receive the pipe was made 3 feet wide on the bottom, with side slope of ½ to 1 foot. The material was a muck for the first half-mile, at the upper end in the well basin, hard gravelly clay and hard pan on the ridges and loose rock and boulders across the washes.

There were three tunnels, each about 300 feet in length, through tough clay and soapstone. They required no timbering. All the work was done by contract, and, while the specifications and advertisements were made to divide the work up into small sections, all the work was contracted to one party, except the steel pipe, which was made a separate contract.

CONTRACT PRICES.

Common earth, 13½ cents per yard.
Ditch work, hard pan, 46 cents per yard.
30-inch cement pipe, laid in ditch, $1.16 per lineal foot.
28-inch cement pipe, laid in ditch, $1.09 per lineal foot.
24-inch vitrified pipe, laid in ditch, $1.20 per lineal foot.
Manholes, $3.00 each.
Bell holes, $1.50 each.

STEEL PRESSURE PIPE.

All pipe under a head of 65 feet or less was No. 14 Birmingham gauge, weight not less than 3.12 pounds to the foot, and all pipe under a head greater than 65 feet was No. 12 Birmingham gauge, weight not less than 4.3 pounds to the foot. All pipe laid with a head of 30 feet or less was laid with a driven joint. All pipe laid under a head greater than 30 feet was riveted together in the trench. The pipe was in lengths of from 21 to 24 feet. All pipe was coated with J. D. Hooker's asphalt coating. An 8-inch blow-off gate was put in at the lowest point of each siphon, and an air-valve where the pipe crossed a ridge between two low points. This occurred in only three instances in the entire line.

PRICES PER LINEAL FOOT.

No. 14, 24-inch double-riveted steel pipe, laid in trench with driven joints, $1.39.

No. 14, 24-inch double-riveted steel pipe, laid in trench with riveted joints, $1.58.

No. 12, 24-inch double-riveted steel pipe, laid in trench with riveted joints, $1.96.5.

Angles and curves, three times the price per foot of the pipe used.

Blow-off gates, $45.00 each; air valves, $18.00 each.

This made the total cost of steel pipe, $25,479.15.

The contracts were signed on January 7, 1892. The work was to be completed by April 10 of the same year. It was practically finished on May 1.

CONSTRUCTION.

F. M. French, of Los Angeles, was the contractor for all the work, except steel pipe, which was made and put in by J. D. Hooker, of Los Angeles.

The contract for the cement and vitrified pipe was sublet to the Pacific Clay Manufacturing Company, a large portion of the vitrified pipe being already made at the factory. Within two weeks 200 feet of cement pipe was being made per day, while a large force of men and teams was opening up the ditch. The entire work was pushed with the same characteristic vigor until completed, with scarcely a hitch anywhere. Many difficulties were encountered, but they were generally provided for in advance, and expensive experiments with large forces were avoided.

The only part of the line that gave us any serious annoyance was the first 1800 feet leading out of the well basin. This was in a black muck full of water, and the bottom of the ditch was so soft that it would not bear the weight of a man. The ditch averaged about 4 feet in depth and 4 feet wide on the bottom, but when I went to inspect it, prior to laying the pipe, about a month after it was dug, I found it closed in to 2 feet in width in many places. We then considered the question of changing the structure at this point to a flume, but, as a flume had not proved very satisfactory in a similar case, we decided to experiment with the pipe, as it was already on the ground. And near at hand there was an abundance of willows, from 3 to 4 inches in diameter. I had these cut into 4-foot lengths and placed crosswise of the ditch, as close as they could be laid, and then placed two 1″ by 6″ boards lengthwise, about 10 inches apart, on top of the willows. To our surprise, we found that the cement pipe, which weighed about 130 pounds to the foot, could be laid on this foundation without difficulty. As soon as the pipe was laid, I had sand and gravel tamped in on the sides to a depth of 14 inches, using about 1 cubic yard to every 4 lineal feet. This may seem to be a reckless expedient, but the pipe has not settled or given us any trouble since, and it has been in use five years. On all grade pipe manholes were placed at intervals of 300 feet, and, in addition, a manhole was placed within 15 feet of each end of each inverted siphon. On the cement pipe these manholes were made by cutting a hole with a cold chisel in the top of the pipe, and cementing on vertically a joint of pipe 2 feet in length, or a sufficient number of joints to bring the top of the standpipe above the surface of the ground. For the vitrified pipe a special joint was made with an 18-inch opening on the side, to which the pipe was attached vertically, as before. Subsequently I had wooden covers made and bolted on the tops of these standpipes with from six to eight $\frac{3}{8}$-inch holes for air vents.

The connections with the steel pipe were made by extending

the cement pipe about 18 inches over the end of the steel pipe. After carefully caulking the seam, a masonry pier, 18 inches in thickness and 4 feet in length, was placed around this connection. On a connection with vitrified pipe a joint of the 28-inch cement pipe was supplied.

TUNNELS.

The tunnels were made 4 feet wide on the bottom and about $5\frac{1}{2}$ feet high. They were lined with 28-inch cement pipe and back-filled with sand to the top of the pipe. The rest of the space was filled with the material excavated.

ENGINEERING.

The writer himself established the center line prior to the commencement of the work, and made out a table showing the station, course, elevation and grade. The additional data for a working section were afterward supplied. The slope stakes were set immediately in advance of the graders by the writer's assistant in charge of the grading. In this connection it will be in order to state that, two years before, a careful preliminary survey was made, with a complete estimate of cost, and the contracts were let on this estimate, subject to any changes or corrections the writer might make during the progress of the work. During the progress of the work he had five assistants. One set the slope stakes, ran all the levels for finishing grades and looked after the graders. Another assistant, who was an engineer, looked after each gang of pipe-layers. There were three gangs laying vitrified and cement pipe and one gang laying steel pipe. These assistants were to inspect every joint of pipe as it was laid, rejecting all imperfect pipe; also, to see that the mortar was mixed in accordance with the specifications, and to see that each joint was properly lined in the trench. They kept a record of the work done, carefully noting any special features. This record was turned over to the writer every time he passed over the line, and if any question arose as to the quality of pipe or character of work done, it was left for his inspection. The assistants were given no authority to finally accept or reject any of the work, a provision of the specifications which proved very valuable, as it made the contractor more careful. The writer went over the work at least twice a week, and in three instances had work taken out after it was supposed to be finished. He crawled through all the grade pipe and inspected it with a torch after it was finished. To some this may seem extreme caution, or lack of confidence in the assistants, but it is believed that the cause of failure in many works of

this kind is the result of carelessness in the details of construction rather than in the specifications, and that success depends upon the thorough completion of every part.

There were instances where imperfect joints were made, that had escaped the notice of the inspectors. One of the greatest advantages of this inspection was, that it made all parties attentive and extremely careful in their work.

The water was run through the line before the work was accepted, and final payment was made 30 days afterward.

COST.

The amount paid for digging ditch, laying cement and vitrified pipe and backfilling the entire line was	$29,085.00
Amount paid for steel pipe	25,479.15
Total construction	$54,564.15
Engineering superintendence, including chief engineer	3,895.00
Preliminary survey	800.00
Total	$59,259.15

DISTRIBUTING MAIN.

The distributing main across the mesa will be, when completed, about 6 miles in length. The first 10,239 feet is of 28-inch cement pipe, the second 10,000 feet 24-inch vitrified pipe and the remainder 18-inch pipe. The 28-inch pipe and 2000 feet of the 24-inch pipe were put in at the same time as the main line (1892), at a cost of $1.33 per foot, complete. The remainder of the 24-inch pipe was put in in 1894–6. The line is located on a grade contour with a fall of 3 feet to the mile, the contour of the ground being followed, so that the cut at any point is not less than 2 feet or more than 4 feet. An avenue 80 feet wide was located, so that there is a 70-foot street on the lower side, which makes it possible to irrigate the upper side of the first lots. At all points where distributing laterals were taken out, a box, 3 feet square on the inside, was placed on the main line, the bottom of the box and the outlet pipe being placed 6 inches below the main pipe. These boxes were made of concrete (1 part cement to 7 parts sand and gravel, plastered on the inside with a mortar of 1 to 1). Cast iron gates were cemented into the side of the box at the end of the laterals. This construction has proved very satisfactory. The cost was about $8 for each box.

Before describing the distributing system, it will be necessary to describe the method of subdividing the land under this system. The method is unique, but as it has fully come up to all expectations, and, in practice, has successfully met all the criticisms that

were offered, the writer has no hesitancy in placing it before the Society as the best method to be used where the land slopes uniformly in two directions. As already stated, these lands had a slope of 150 feet to the northeast. In addition to this, they were slightly undulating at right angles to the slope, so that it was not always certain that the water would run at right angles in one direction from a lateral pipe running down this slope, and, even if it did, there would have to be a lateral for each tier of lots. As these laterals cost about $2500 per mile, it was suggested that a subdivision be devised in which one lateral would accommodate two rows of lots. It was found that by this means between $8000 and $10,000 could be saved in the cost of laterals on this tract. The following plan of subdividing was devised:

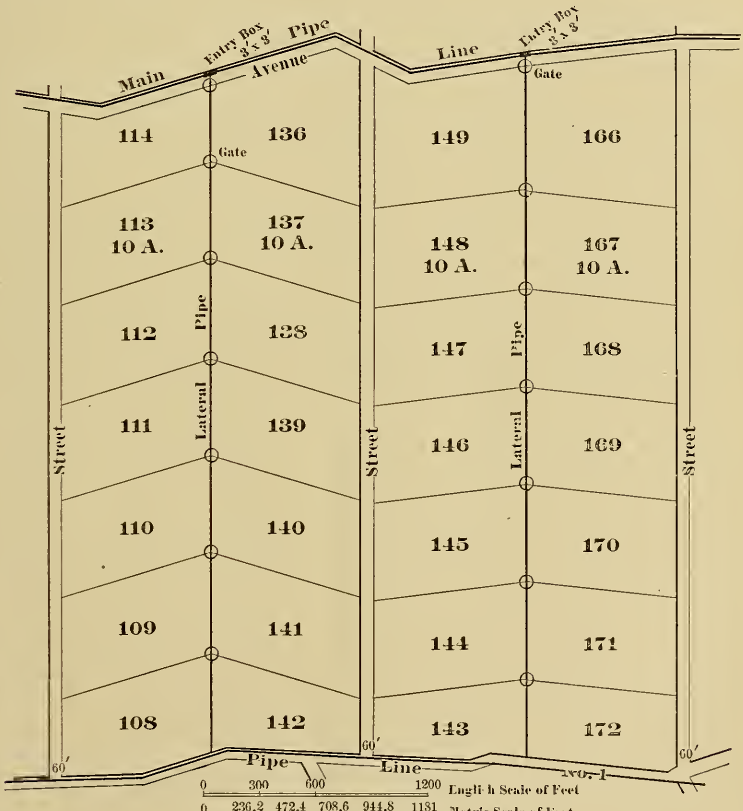

FIG. 3. PLAN OF SUBDIVISION.

The street and lateral lines of pipe were placed as nearly as possible at right angles to the main line, and the corners of the

lots were moved up the slope along the laterals, so as to insure a fall of not less than 18 inches along the upper line of each lot. Contour lines were run, and the lines established on each block, in accordance with the slope of the ground.

As is usual with all new departures of this kind, many objections were offered. As the tract was to be set out to trees, it was claimed that the lots should be square, but it was easily shown that the rows would be just as straight in parallelograms. As a result, these lots have commanded the highest prices, as they furnish more opportunity for the exercise of taste in their improvement. More than half of the tract is now planted, there are many bearing orchards, and their appearance is a sufficient commendation of the plan.

The distributing laterals are made of 7 and 8-inch vitrified pipe, laid about 2 feet below the surface. The outlet gates, at the upper side of the lots, were made by building square brick boxes in the line, extending 15 inches above the surface and having flumes attached to each side. These are called head flumes. They extend along the upper side of the lots. They are made of wood, cement and vitrified clay, and they vary in size from 8 to 12 inches square, to correspond with the grade. I prefer the cement flume, which costs about 18 cents per lineal foot. The sides are 4 inches and the bottom 2 inches in thickness. About every 6 feet outlets were made, from which the water runs down small furrows, requiring about 10 to 12 hours to cross a lot 528 feet wide. The water is turned out of the lateral by a cast iron gate cemented into the lower side of the outlet box. The usual irrigating head is 25 miner's inches, equal to ½ cubic foot per second. Young orchards are irrigated every 30 days, during the summer; older orchards about once every 6 weeks. The equivalent of from 2½ to 3 inches depth of water is put on at each irrigation.

Paint Tests.

Discussion by Mr. W. J. Wilgus of Paper by Mr. Max Toltz.*

[Read before the Civil Engineers' Society of St. Paul, November 1, 1897.†]

As the results of my own experiments and observations differ somewhat from those of Mr. Toltz, I deem that the following remarks may be appropriate:

Mr. Toltz's recommendations, briefly stated, are as follows:

1st. Priming coat of linseed oil.

2d. Coat of asphaltic varnish.

3d. Coat of graphite paint.

The use of a priming coat of linseed oil is discountenanced by many engineers as tending to act as a "catch-all" for grit, dirt, etc., which are embalmed in the oil as it hardens, and are never perfectly removed. There is, however, the more serious objection pointed out by Mr. J. Spenrath, in his prize essay on "Protective Coverings for Iron," published in the *Railroad Car Journal*, that linseed oil, without a pigment, never thoroughly hardens, and ultimately blisters the succeeding coatings of paint. In the writer's opinion, the preferable method is to enforce rigidly that clause in our specifications which provides that the surface of the steel shall be thoroughly cleaned by the sand blast or other approved method before the application of the priming coats at the shop, even if the manufacturer must be paid an additional price for so doing.

The use of asphaltic varnish for the first coat of paint is, from my observation, inferior to that of a heavy coat of red lead and oil applied to a clean, dry surface. The assertion of Mr. Toltz that many progressive engineers are discarding the use of red lead is, I consider, unsupported by facts. Mr. Walter Berg, Principal Assistant Engineer Lehigh Valley Railroad, has made a careful, exhaustive, and intelligent research into the merits of various paints for railroad bridges, and, in an article published about a year ago, he states that replies to inquiries as to the prevailing practice on about 30 prominent railways show that over 80 per cent. recommended using red lead and oil for priming coats. Moreover, as a result of his extensive study of the problem, he endorses that practice. Spenrath holds that the sole weakness of red lead lies in its being attacked by hydric-sulphide, but with a

* Printed in Journal of June, 1897, vol. xviii, No. 6.

†Manuscript received November 20, 1897.—Secretary, Ass'n of Eng. Socs.

suitable second and third coat of paint this objection is of little paints, and submerging them for two weeks in water containing weight. Neither does Mr. Toltz produce any evidence supporting his adverse opinion of red lead and oil.

At the last annual meeting of the Master Car and Locomotive Painters' Association the preponderance of evidence submitted by various members went to prove that red lead and oil, as a protective coating for the metal parts of cars and trucks, is unsurpassed. Mr. Toltz remarks that the fact that advocates of red lead and oil had begun to add carbon black and graphite to their paint is a sure indication of their own disbelief in red lead alone as the best pigment. This remark seems to have as much weight as the one to the effect that the engineer using salt for mixing mortar in freezing weather really doubts the value of cement as a binding material. Lampblack and graphite are often used with red lead and oil, not necessarily to improve the lasting qualities of the pigment, but to make the paint work smoothly and evenly. Their use certainly in no way reflects upon the basic material as a preservative.

The experiments and examinations of various paints, in actual use by the writer, confirm the above conclusions. Tests made by covering clean, bright steel plates with two coats of 12 different one-half ounce of hydrochloric acid to one gallon of water, disclosed the fact that the relative merits of the paints thus tested were as follows:

1st. Red lead and linseed oil.
2d. Asphaltic varnish (pure, genuine) paints.
3d. Carbonizing paints.
4th. Graphite paints.
5th. Iron oxide paints.
6th. Cheap patent paints.

These tests gave excellent comparative results, as they emphasized the value of the three cardinal virtues of a good paint:

(a) Good adhesion to the metal.
(b) Lack of porosity.
(c) Resistance to chemical and galvanic action.

The absence of any one of these three qualities, even if the other exist, will cause the paint to fail.

Observations of paint on many steel bridges confirm the conclusions above stated.

The color of red lead is of course objectionable, and for second and third coats the use of asphaltic varnish paint is to be recommended. During the past four years the majority of the new bridges on the Rome, Watertown and Ogdensburg Railroad,

which were originally coated with cheap patent paints, have been repainted with a paint prepared from a formula given by Dr. C. B. Dudley, as follows:

4 pounds of pure lampblack ground in raw linseed oil.
$\frac{7}{8}$ gallon genuine asphaltic varnish.
$\frac{1}{4}$ gallon pure, refined, boiled linseed oil.
$\frac{1}{4}$ gallon drying japan.

These ingredients were purchased and mixed by the railroad company, and cost from 60 to 80 cents per gallon. One gallon covered about 350 square feet, and the cost of cleaning the surfaces and applying one coat of paint cost, on an average, 60 cents per net ton of bridge material.

The results from the use of this paint have so far been excellent.

To summarize, the experience of the writer has led him to favor the following practice:

FOR NEW WORK.

1st. Thoroughly clean the surface with the sand blast and apply, at the shops, a priming coat of red lead and linseed oil and a second coat of asphaltic varnish, using special care where surfaces come in contact and are shop-riveted, or at parts that are inaccessible for field painting.

2d. Apply a third coat of asphaltic varnish paint, after erection.

REPAINTING BRIDGES.

If in bad condition, clean all surfaces with the sand blast and use a priming coat of red lead and oil, and a succeeding coat of asphaltic varnish, as specified for new work. In exposed places a third coat of asphaltic varnish should be used.

If the old paint is in fair condition, clean all surfaces from dirt, dust, scale, etc., and, after touching up all bare or defective spots with a preliminary coat of asphaltic varnish paint, apply one coat of the same paint.

The company should purchase and mix all ingredients of the paint to be used, taking great care to obtain only the pure, unadulterated articles. The majority of the patent paints that flood the market simply disguise, under euphonious titles, a conglomeration of worthless materials.

The importance of this subject, treating as it does of the armor that is the sole protection of our "permanent" steel bridges against the ravages of their mortal enemy, rust, is my apology for thus encroaching on your time and good nature.

VISITS TO SCIENTIFIC INSTITUTIONS IN EUROPE.

By Prof. Edward W. Morley, Ph.D., LL.D., Honorary Member of the Civil Engineers' Club of Cleveland.

[An address delivered before the Club, November 9, 1897.*]

Ladies and Gentlemen:

In an emergency caused by a disappointment to your Programme Committee, I agreed to say something to you about some of my visits to certain scientific institutions across the water. That one which, if I could tell you the whole story, would perhaps be the most interesting of all to this audience was the Imperial Institute at Berlin, the Physikalisch-Technische Reichsanstalt. It was planned mainly by the great Hermann von Helmholz, and was founded by a most noble donation from Siemens, whose name is well known to all electricians, as well as to other scientific men.

This institution is under the care of the Government. It is, as its name declares, an Imperial Institute. Its duties are twofold, as the adjectives in its name may indicate. One part of its functions is the study of many refined physical problems, some of them too extensive or too costly to be dealt with by private means, or even by the semi-public means of the great German universities. Another important labor of the institute is the verification of almost any precise mechanism or apparatus submitted to it for the purpose.

In order to illustrate to you the extent and variety of the work done in the Reichsanstalt, I took the published list of the work accomplished by it during the year in which my visit fell, and began to copy the titles, but it is too long to read to you.

Among the more strictly scientific labors it was pursuing, I will name a few. It was engaged in measuring the expansion of water more accurately than had been done before. It was measuring the weight of a cubic foot of steam, with reason to hope that the accuracy attained would surpass that attained even by that great master of accuracy, the famed Regnault. It was studying the change of elasticity of a glass bar or tube caused by changes in temperature; its elasticity at the freezing point and its elasticity at the boiling point of water differ 10 per centum in some of the glasses which were used, and but 1 per centum in others. It had prepared a most elaborate normal barometer, and

*Manuscript received December 13, 1897.—Secretary, Ass'n of Eng. Socs.

had compared with this the working barometer which is used for all ordinary purposes. It had made three series of measurements of the expansion of the three steel screws used in Fizeau's wonderful apparatus for measuring expansion. All this is work of a high order, and it is work very necessary to have done; and the Reichsanstalt has the facilities for doing it. They have a personnel of men competent to do it, and the superintendence of a man well fitted to lead in the doing it.

As a sample of the other kind of work done there, almost anything which you can mention as desirable to be verified can be verified there. They verify thermometers, or determine their errors, and furnish a table stating what corrections are needed for these errors. They verify the accuracy of screws; the leading screw of a lathe, for instance, or the screw of such a micrometer as has been made by two of our Past Presidents for the Yerkes Observatory. They measure the expansion of steel bars designed to become scales by receiving an accurate graduation into millimeters or other lengths, or to be used in making an astronomical pendulum. Riffler, for instance, has had the expansion of the steel rods of his pendulums determined in the Reichsanstalt. They investigate alloys desired for special purposes, or required to possess certain specified properties. One gentleman desired an alloy which should have no magnetic properties, and the Reichsanstalt studied the matter and furnished such an alloy. They investigate gyrometers, instruments for indicating the number of revolutions of a rotating axis by a continuous indication. They verify tuning-forks. If one is constructed to make 500 vibrations in a second, they can determine the actual number almost to the hundredth of a vibration in a second. They determine the durability of incandescent lights, and also their efficiency. All such questions and such forms of apparatus are submitted to the Reichsanstalt, and you would be surprised to learn for how small a fee the desired information is afforded. As you see, this is a pretty wide field of activity. In order to do such work, they employ a great number of trained scientific men. In Germany a trained scientific man will accept such a position, because it is considered honorable, and because it gives him a recognized and desirable social position. So the institution can command a high degree of talent and training for its work.

One day I met, in Berlin, two Americans whom I had the pleasure of knowing in this country, and we visited the Reichsanstalt together. That which most interested us was the magnificent institution as a whole. One most interesting apparatus was

one designed for the establishment of a standard of light. You all know that it has been proposed that the ultimate standard of light for all measurements should be the light given out by a certain area of platinum at its melting point. It will probably be some time before this proposed standard can be conveniently and practically applied. The Reichsanstalt has suggested, and is trying to prepare, an alternative source of light designed as a standard for comparison in all accurate measurements. This standard is one in which a given area of platinum is heated, not to its melting point, but to that temperature at which the quantity of light radiating from it and also passing through a given absorbent screen shall be precisely one-tenth of the whole energy radiated. Their screen consists of a tube, closed at the two ends by plates of quartz of a determinate thickness, and filled with distilled water; and the standard of light which they hope to make practical is to be derived from a given area of platinum heated to that temperature at which this screen of quartz and water shall transmit one-tenth and absorb nine-tenths of the whole energy radiated. In the apparatus which so greatly interested me four different observers were to look, at the same time, at this source of light, each having his different measurement to make.

The apparatus, too, with which they compare thermometers seemed to me a most interesting apparatus. They have means for maintaining constant the temperature of a liquid medium in which they place a number of thermometers to be compared, and the apparatus will maintain some temperatures constant within one-hundredth of a degree for hours. Think of the skill, think of the apparatus required to do that, and then think of a building larger than our City Hall, filled with such skill and such apparatus, and you have a suggestion as to what this Reichsanstalt really is.

In Paris there are two laboratories which greatly interested me. One of them is the physical laboratory of the Sorbonne. I had the pleasure of meeting there the professor of physics, of whom you have all heard within the last few years, Lippman, the inventor of the process by which photographs can be taken which, properly used, can be made to throw on the screen an image of the original in the colors of nature. Professor Lippman was very kind. He desired to have me shown around his laboratory for an hour, while he made ready the photographs and lantern, which he was to show me afterward. He therefore asked an assistant to accompany me, but, on reflecting that his assistant could not speak English, he dismissed him and prepared to go with me himself. Of course, I relieved him of that loss of time

by telling him that I could understand his assistant's French, though I could not guarantee that he would understand *my* French.

When I was brought back to Lippman's room he showed me twelve photographs projected on the screen. They are not such photographs as can be framed and hung on the wall; you cannot see them as you see water-color drawings, or as you see the Zurich photochromes.

In order to get the color of the original, your eye must take that position in which you have specular reflection from the source of light. Now, as an orator, I am bound to assume that you all know what specular reflection is. If you let the sun shine on a mirror, it reflects the rays of the sun in one definite direction. If you stand within this path, where you can see the image of the sun in the mirror, you see some part of the mirror illuminated by specular reflection,—namely, that part of it which the image of the sun seems to cover. And if this mirror were one of Lippman's color photographs, you would see the vivid colors of the original only where, in the mirror, you had seen the sun's image.

A water-color drawing is usually seen by what is called irregular reflection. The rough surface of the paper receives light from perhaps a single source, but reflects it in every direction. Whatever your position, you see the paper and the colors on it. But if a mirror is so perfectly polished that no irregular reflection is produced by imperfections remaining, and if it is lighted by a single small source of light, you can see it only in that position in which you can see the reflected image of the light, and you can see only as much of it as is covered by this image. To see the whole mirror, you must have a source of light so large that its reflected image seems to cover the whole mirror. This cannot be accomplished with any practicable source of *intense* light, and Lippman's photographs require an intense light.

So Lippman's color photographs cannot be seen with the unaided eye, for the simple reason that we cannot procure a light large enough to illuminate the whole picture by specular reflection. The eye is too small. But if we put the photograph in the lantern, where it is illuminated from a source of light so wide that every part of it can return light to the projection lens, we can put on the screen a sight of the whole photograph, illuminated by specular reflection, and the whole audience can see the colors of the original objects.

These colors are wonderfully perfect. Lippman showed me a pair of photographs of a bouquet of bright-colored flowers.

The first photograph was taken indoors, by diffused daylight. I thought it was a magnificent reproduction of natural colors. Then he showed me the second photograph of the same bouquet, in the same aspect, but in bright sunlight. I am sure, could you have seen it, you would have been as delighted as I was; perhaps you would have been as much instructed as I was. I suppose that most of us seeing a bouquet in a good light, though not direct sunshine, and afterward seeing it in full sunshine, think its colors are the same.

Such is the influence of prejudice. These color photographs show most brilliantly that objects in sunlight and in diffused daylight by no means have the same color. But most of us, except an artist in water-colors whom I see present, no doubt are so under the influence of prejudice that, having seen a purple flower, we suppose it is always purple, and always the *same* purple.

> "A primrose by the river's brim.
> A yellow primrose was to him,

and it was always the same yellow. I was surprised to see the wonderful difference in absolute color when the object was placed first in one light and then in another.

Flesh-tints, also, were reproduced with wonderful fidelity. It is not yet possible to take portraits; the exposure required is too long. But Lippman avoided this difficulty sufficiently to enable him to show the capacities of his process in reproducing tints which are so difficult as flesh-tints. He did this by photographing a young girl lying on the grass among flowers. She could not maintain absolute repose, but she was so supported, and the area covered by the image of her face was so small, that the motions inevitable in an exposure of five minutes did not interfere with the general pictorial effect, and the flesh-tints seemed to be perfect.

There are other laboratories in the Sorbonne. In one of them I had the pleasure of meeting a gentleman who has done some of the same sort of work as that which I have done with oxygen and hydrogen. But I must not weary you by describing them.

Another institution in Paris which I must pass without description is the Conservatoire des Arts et Métiers. But I desire to mention a trifling incident which illustrates the exquisite courtesy which it is fair to expect in France. I was looking at the balance used by Regnault, of great interest historically, of special interest to one who has used a balance as I have done. It was so protected by a silk cord that I could not approach it as nearly as I desired, and a keeper or janitor who was present was

urements which is worth translating, the meter is the only standard of length which is not ambiguous, and the same is true of the kilogram. How many different pound weights are there?

Now, as I said, the principal civilized governments united in forming this International Committee of Weights and Measures. This international committee, with the help of a French committee, have performed their task, and the mechanical and physical and practical work has been done a few miles from Paris, at Sèvres, in the Pavillon Breteuil, which was once a fine summer palace. This is now the home of the International Bureau of Weights and Measures. I went there one day, fresh from a long stay in England. In that country, if you desire access to almost any of the places which were likely to interest me, affidavits of respectability, in the shape of letters of introduction, are most essential, and I went to England in such health that letters of introduction were far from my thoughts. I went up to the high fence around the International Bureau without much expectation of getting access. In fact, one day I went there, and went away without even making application for admittance. But on another day, as I approached the gate, a gentleman who had been standing there was just going away as he saw me. He courteously lingered, and turned back to the gate. I told him that I was a stranger, and that I had followed their work with great interest, and wished to see what could properly be shown to a stranger. I could not suppose that he had ever heard my name; but I do not know how a man could have received an acquaintance with more cordial courtesy than he showed me. He welcomed me; he introduced himself to me, and introduced me to the head of the Bureau and to the third of the three scientific men of the establishment. Then the three took turns, each showing me that part of the equipment with which he was most conversant. I saw nothing abroad which interested me more than this institution, but I could not hope to transfer this interest to you without diagrams and photographs. There was the comparer with which they have verified the length of those wonderful platinum-iridium meters, of which our own Government has received two or three. I had seen the meters which our own Government received. I had been invited to Washington, to be present when the standard meter was to be unpacked from the box in which it had been sealed at this International Bureau at Sèvres. The superintendent of the Coast and Geodetic Survey, desiring to have some ceremony testifying to the importance of the event, had asked the heads of bureaus at Washington whose duties made them inter-

unable to permit nearer approach without orders from the office, to which he directed me. As I was going upstairs toward the office I met a gentleman coming down. The workman's French was not that of Ollendorff, and I had but a vague idea where to find the office, and so asked this gentleman if he would direct me. He spoke such French as I could easily understand (although not like that of Ollendorff), and said to me, "I am from the office; perhaps I can spare you the going upstairs to it?" I explained, and although he was just leaving the building for other duty, or perhaps pleasure, and although a word to the janitor would have done all I had asked, he took half an hour to show me all I desired to see, and endeavored to keep me longer. As he did not know my name, and as my name could have made no impression on him if known, this may be taken as a sample of the courtesy which is given to strangers by gentlemen in France. It was consistent with my uniform experience in that country; my experiences in Germany were not so pleasant.

The other institution in France which interested me was the International Bureau of Weights and Measures. Some twenty years ago, most of the governments of the larger civilized states united in appointing an International Committee of Weights and Measures, in the hope of preparing accurate copies of the meter and the kilogram.

There is no measure of length, except the meter, which is not too ambiguous for general use. I once read a statement which had been copied from German into French, and then from French into English, which gave a certain length in inches and thousandths of an inch. I was interested to know the precise length intended. The question to be answered by conjecture was, What foot and inch were those used in the statement—the English (for the statement is now in English) or the Paris foot (for the statement was last in French), or one of the many various German standards of confused length (for the statement was first made in German, and almost every German petty state had its own contribution to the confusion of standards of length)? The only solution of the whole matter was, that the truth could not be learned from the announcement, unless I could find whether the Austrian author had used the Austrian standard, or that of Heidelberg, where he wrote; or that of Leipsic, where publication was made; what course the French translator took, and what the English. If Mr. Warner wrote the statement, and it was published in New York, conjecture would be safe; or if an Englishman wrote and London published. But when you consult the literature of precise meas-

ested in standards of length or weight, and the presidents of societies of engineers, and some of us plain professors also interested in such standards, and I had the honor to be among the latter. The seals were broken in the Cabinet room by the President of the United States and his Secretary of State, and an instrument was drawn up and attested by the signatures of all the gentlemen present. That was my first acquaintance with the platinum-iridium standard meter of the United States, and it was most interesting to see the apparatus used in making it the most authoritative standard of length now existing within our country. I saw also at Washington the platinum-iridium kilogram which had also been sealed up at Sèvres and sent to this country and opened at the same time. On my visit to Sèvres I saw a most consummate flower of mechanical skill in the four balances with which the work on that kilogram and on the smaller weights, required in the investigations, had been accomplished. These were balances nearly like the one which I used for some time. They have brought a new precision into the art of weighing. I suppose scales which weigh a ton of coal within 10 pounds are as accurate as commercial scales of that capacity need to be. Now, scales weighing a ton of coal would have to indicate the difference produced by adding to their load a piece of writing paper a quarter of an inch square, in order to equal, in precision and delicacy, the four balances which I saw at Sèvres. One illustration of their accuracy has been mentioned several times. I have mentioned it in this place. I may remark that I once heard this illustration repeated, to my no small amusement. I sat at a banquet and heard a physician of this city tell of a wonderful balance in one of the departments at Washington, which had the degree of accuracy which I will mention shortly, and I sat pleased and silent, for that balance was in my laboratory, and there was none at Washington. The story which the physician told was this: These balances are so delicate that, if you first put two one-pound weights side by side on one pan and counterpoise them, then, if you put one of the two weights on top of the other, the counterpoise will be too heavy, for one of the weights is now farther from the center of the earth than before, and the action of gravity on it is lessened. Such an infinitesimal as this is quite within the delicacy of the instrument. I do not mean to say that one, or even ten, weighings would be sufficient to determine so small a difference. It is to be detected only by long and painful labor. But the error produced by weighing two pound weights, sometimes side by side and sometimes one upon the other, is a

quantity *capable* of being detected by this balance, and it is a quantity which is to be considered in the reduction of all weighings made with it.

There was a barometer there the like of which has not been produced elsewhere, and an air-thermometer like the barometer. Regnault said, some fifty years ago, that between the freezing and the boiling point of water it was hard to measure a temperature much closer than a tenth of a degree. And he was right. But the Bureau at Sèvres has labored at this matter until, within those limits, it is possible to measure to the hundredth of a degree more accurately than to the tenth of a degree fifty years ago. A great increase of our knowledge of the behavior of materials will thus result from the investigations at Sèvres.

One thing which I saw at Sèvres gave me a feeling of sadness. Years ago I had devised a method of determining the weight of a cubic decimeter of water with great precision. I was pleased to see that most of my method had been reinvented at Sèvres, and saddened that I had not had, and was not likely ever to have, time, means and assistance to do so interesting and desirable a piece of work myself.

I must pass on to speak of some things in England. There were many things which I should like to mention. It would be pleasant if there were time to speak of Lord Kelvin's laboratory and lecture room at Glasgow, or of the fine laboratories at Manchester, and of interesting memorials of Cavendish and Davy which I saw there, the property of Professor Dixon, with whom I spent a most pleasant half-day. I should like to speak of King's College and of many things in London, but time fails me. I should like to speak of the Royal Society and of the Royal Society Club. This is the most interesting and important learned society in a country where, as I said the other day to an Englishman, all the scientific men in the country can get together every Thursday afternoon, if they choose. The country is not so widely extended as ours. We have to be content to meet a few scientific men once a year.

The British Association for the Advancement of Science made a great impression on me. In England almost all the scientific men—the greatest as well as the lesser—get together at these annual meetings. There is a wonderful power in this. The British Association is the only great success of that kind on the face of the earth. Similar French and German societies are qualified successes. Our own is but a qualified success. But in England every scientific man thinks it a duty and a luxury to

go to these meetings, and there is a wonderful inspiration in the assembly.

One matter of which I wish to speak is the Royal Institution in London. If there is any place in London in which an American ought to feel at home, it is the Royal Institution. It was founded by an American, Benjamin Thompson, afterward Count Rumford, of the Holy Roman Empire. I do not know what was his precise aim. The Institution is now somewhat unique. It is in some sort a scientific and literary club. Any one seems to be elected to membership on application, I think as freely as he could be admitted to our Case Library on paying his fee. The building has a library and a pleasant reading-room well supplied. It has also a good many Americana, including letters from Franklin and Washington, as well as other matters especially interesting to Americans. It has also important laboratories, in which some of the most memorable work yet done in science has been accomplished. You will agree with me when I recall to your minds that here Sir Humphry Davy worked and here his greatest discovery succeeded him in the person of Michael Faraday. At the present time Dewar is professor of physics here, and Lord Rayleigh, the discoverer of argon, is professor of chemistry. Lord Rayleigh's work is done at his private laboratory, an hour from London, which, of course, I could not see.

The munificence of an eminent English scientific man has lately added a new laboratory to the resources of London science, and this new laboratory is closely adjoining the older laboratories of the Royal Institution and under the management of those professors of the Institution who were just named, so that practically it is a new laboratory of the Royal Institution. This laboratory I did not see.

In the older laboratories of the Institution Dewar has done a great and important work in the liquefaction of gases. It is not that on precisely the process of liquefying gases he has added very much that is new, for gases had been liquefied by others; but, using liquefied gases as instruments of research, he, with certain gentlemen whom he has associated with him, has done a very important and interesting work. He showed me, partly with his own hands and partly at the hands of an assistant when he himself was busy, some experiments which would charm you, I am sure. First, he showed me the liquefaction of oxygen by an apparatus which we could set on this table, and liquefied a couple of ounces of oxygen within twenty minutes. In this

apparatus liquefied carbonic acid from an iron cylinder is made to stream through a long copper spiral, closely wound in such a way that, issuing from the lower part of the spiral, the gas is cooled by its sudden expansion, flows back over the other part of the spiral and cools it as well as the gas which will issue from the jet in the next moment, and in a few minutes you have this cooled to the temperature at which carbonic acid boils at atmospheric pressure. That cooling is applied to the second spiral, in which oxygen, at a pressure of fifty atmospheres, passes downward and is then permitted to expand to the pressure of the atmosphere. Having been already cooled to the boiling point of carbonic acid, the oxygen is soon cooled down to its own boiling point at atmospheric pressure, and then falls in liquid drops into a glass tube, in which you collect a shower of liquefied oxygen. The liquid was somewhat turbid. The gas had been procured, compressed in an iron reservoir, from some factory where oxygen is prepared for use in calcium lights, and contained some impurities. The liquid was filtered through paper, just as water might have been filtered, and was then a transparent, colorless liquid—a magnificent sight. In that was dropped a half-teaspoonful of absolute alcohol. Absolute alcohol does not freeze easily, but, when dropped into liquefied oxygen, it solidified, and then cracked into smaller angular fragments, as melted glass dropped into cold water cracks and flies to pieces. We took the solid absolute alcohol out and could not burn it till after we had warmed it to its melting point; it would not take fire. We dipped cotton wool in the liquid oxygen and touched it with a flame; it burned almost as if it were gunpowder.

Then I saw another apparatus for liquefying gases, used in researches at low temperatures. It had cost several thousand pounds sterling. One part of this apparatus was a gas engine of 25 horse-power, by means of which air was compressed to 200 atmosphere—to a pressure of 3000 pounds to the square inch. This compressed air was led through a tube, in which it was partly dried, and then through a spiral, like that which I mentioned before. The air was permitted to escape from an aperture at the lower end of this spiral, and the cooled gas then streamed up along the spiral and cooled it. In fifteen or twenty minutes, by maintaining the pressure of the air at 3000 pounds to the square inch and constantly releasing the gas at the lower end of this spiral, the spiral and the gas were cooled to the temperature at which the air liquefied and dropped like water. This apparatus is, of course, not portable, and its mechanical efficiency is but

1 per centum. To go in one step from ordinary atmospheric temperatures to the temperature at which liquid air boils at atmospheric pressure is a very long step. Something of efficiency must be sacrificed.

Then I saw a third apparatus, in which a double cooling was employed—first, from ordinary temperatures down to 50° or 100° Centigrade below the melting point of ice, and then, through a second step, down to the temperature at which air boils at atmospheric pressure. In this apparatus the mechanical efficiency was as much as 60 per centum.

I saw some of the apparatus which Davy used. But little of it remains—simply some suggestions of the great battery with which he decomposed the alkalies and discovered the alkaline metals. Some pieces of Faraday's apparatus were also to be seen.

Dewar was interested in the so-called X rays, and showed me the result of some experiments which he had just made on the transparency of different elements to these remarkable radiations. He made this the subject of a paper read before some learned society in London.

One other place which I visited in London was the office of the Warden of the Standards. London is a place which has grown. There is but little there which was built to order for its present use, one is tempted to think. Things are not often torn down in London; they are strong and lasting enough to be used for another purpose. And this Bureau of Weights and Measures, the office of the Warden of the Standards, was most interesting for this reason: One of the rooms in which standards are kept which have come down from the time of Queen Elizabeth is a chapel which is 600 years old. The very word "old" has a different meaning in England from that which it seems to possess in this country. Here the word "old" carries with it the suggestion, "Throw it away; get something new." With them the feeling is, that what is old is sacred, endeared, consecrated. The phrase "old fellow," as a term of endearment, was not invented on this side of the water. There it is at home; it is appropriate. I soon began to feel that there is no hope of salvation for a man in England who goes to a church less than 200 years old. In that old and venerable chapel, worthy of veneration, the old pound weights, the old gallons of Queen Elizabeth's time, seemed consecrated; seemed to have a glamor of romance and poetry about them. I never knew, till after visiting such scenes and seeing in them these special objects, how the meaning of the English language may change with change of longitude.

DISCUSSION.

Question.—I would ask the Professor if the tumbler of liquid oxygen is under atmospheric pressure.

Dr. Morley.—Yes.

Question.—What is the process by which it is again evaporated? What is its behavior?

Dr. Morley.—The liquid oxygen is kept and manipulated in glass vessels holding, perhaps, a pint and having double walls. Between the two walls is a very high vacuum. When the liquid air or oxygen is in such a vessel, protected by the non-conducting vacuum, very little heat reaches it, and it evaporates quietly at the surface, just as water evaporates from a tumbler of ice-water. The liquid oxygen, so used, looks like water; unless you notice the temperature of the liquid, you might well mistake it for water. But if you pour some of it into a vessel which does not protect the oxygen from the access of heat, it boils rapidly and disappears. In a common test tube a tablespoonful of liquid oxygen might last three minutes; in one of the vacuum jacketed holders a pint might last half a day. This is merely my conjecture; I have not seen the experiment made.

By Professor Langley.—Was there any visible tint of the oxygen?

Dr. Morley.—No; it looks just like distilled water.

Professor Langley.—Have they succeeded in producing hydrogen in anything more than a liquid spray?

Dr. Morley.—Dewar discussed that point; he had not, at that time, collected drops of liquid hydrogen in a tube where they could be seen.

Mr. Barber.—What is the lowest temperature which they are willing to give?

Dr. Morley.—The temperature of 220° Centigrade below the melting point of ice can be maintained at will by the evaporation of liquid oxygen at about a thirtieth of the atmospheric pressure. The temperature of minus 240 can be attained for a moment by cooling hydrogen down to minus 220, after compressing to perhaps 100 atmospheres, and then suddenly releasing it from this pressure. By a similar use of the newly discovered gas helium the temperature of minus 260 can be attained for an instant. Minus 273 is the ultimate limit, according to our present insight into the matter.

Dr. Howe.—I would ask Dr. Morley if it is not possible to see the colors in Lippman's photographs without a lantern?

Dr. Morley.—Yes; you can see the colors of some small

part of the photographs in their proper brilliancy, and the colors of the rest obscurely and somewhat altered in tint. In order to see properly the colors of the whole photograph at once, you need a source of light so large that its image in the reflecting surface of the photograph is as large as the photograph.

Lippman has been successful in reducing very much the time of exposure required to produce his photographs, and had some reason to hope for such further reduction that it would be possible to take portrait photographs.

It was interesting to hear him tell of his long search for a photographic film which should be sufficiently transparent. The film he uses has to be much thicker than in ordinary photographs. In those we have areas which are transparent and areas which are opaque; the contrast is sufficient if the transparency is not very great, and the opacity answers, even if the film is very thin. You may roughly compare an ordinary photograph to a gauze curtain having sewn to it a pattern cut out of some black cloth. With a light back of the curtain you can see the pattern clearly, even if the gauze stops a good deal of the light. But a Lippman color photograph is a much more complicated structure. Let me try to explain it, so that you may see why so thick and transparent a film is required. Let us imagine the thickness of the photographic film to be magnified a million times, so as to avoid speaking of minute distances. Then, at a point which shows yellow in the photograph, there would be seen something which I may compare to 100 or 200 gauze screens, all parallel to each other, all equidistant, one behind the other, and with an interval of 11 inches between successive screens. Each screen is to reflect light to the eye in front of the system. The whole system must be transparent, so that the light reflected from the screens most remote from the eye may pass through the intervening screens and reach the eye of the observer.

The colors of these photographs are due to the interference of the light reflected from these different reflecting layers, likened to the successive gauze screens. In the case just mentioned, where the distance separating the successive screens is 11 inches, a wave-disturbance which had a wave-length of 22 inches would be reflected from the hundreds of different surfaces, so that all these reflections should add their separate effects and give the sensation of yellow; but a wave-disturbance of some other than 22 inches wave-length would be quite lost by the counteraction of the separate reflections. So no color except yellow would show at the place in question.

These screens are produced within the substance of the photographic film. Let us imagine this substance to be represented, in our crude comparison, by filling the space between the gauze curtains with solid glass, or celluloid, or some other transparent substance. Then the light reflected from those screens more remote from the eye must pass through hundreds of screens, and also through a certain thickness of glass. The whole structure of screens and intervening substance must be transparent in a high degree. So Lippman's film must be very transparent, and must develop reflecting surfaces (at intervals of the thirty-five-hundredth of a millimeter) which have sufficient reflecting power and not too much opacity; for the light reflected from some of them has to pass through a multitude of others. It was very interesting to hear Lippman tell of his long search for a proper material.

I intended to say a word about the maker of the exquisite balance which was for a time in my laboratory, and those which are at the International Bureau of Weights and Measures. I went to see Rueprecht in Vienna. When I handed him my card he knew me, for we have had a good deal of correspondence. It was very pleasant to see his expressions of delight at seeing me, and my delight was as great as his. He knew well how much I like his balances, and showed me everything which could interest me. But it is too late now to say more.

I think most of us are well satisfied with our own country. I know that I am. I like to live in America; but it is to be confessed that Europe has, in some directions, the great advantage of an earlier start. The material equipments bestowed on the advancement of science, the leisure and the assistance afforded to a professor in a university, excited my envy and despair. Here we have reached the point where it is not too hard to get money for a university for—*the instruction of undergraduates.*

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THE STRENGTH OF SEWER PIPE AND THE ACTUAL EARTH PRESSURE IN TRENCHES.

BY FRANK A. BARBOUR, MEMBER OF THE BOSTON SOCIETY OF CIVIL ENGINEERS.

[Read before the Society, November 17, 1897.*]

VITRIFIED clay, owing to its many excellent qualities, has been, and will be, extensively used in sewer construction.

Resisting well the wear of the stream, and proof against chemical action, it is economical and sanitary; and the smooth salt-glaze of a clay pipe affords a low coefficient of friction.

As an offset to these excellent qualities, however, little is known of its strength, and the constructing engineer of to-day, attacking the more difficult problems with their quicksand, deep cuts, water and underdrains, is often worried as to the possibility of failure of his pipe. If he doubts the safety of standard pipe he uses double strength, or resorts to concrete. The former costs usually 75 per cent. more than standard pipe, and the latter a still greater amount. Assuming the cost of pipe to amount to 12 per cent. of the total cost of average sewers, it appears that about 10 per cent. is added to the total cost by the use of the thicker pipe or concrete, and it is therefore an important question to determine where and under what circumstances it is necessary to use other than standard pipe. Again, since failures have occurred in several places with the double-strength pipe, it is important to determine whether these were due to poor pipe or poor construction—whether, in short, it is possible to get sufficient pressure on a good pipe, well laid, to break it.

*Manuscript received October 25, 1897.—Secretary, Ass'n of Eng. Socs.

As an answer to some of these questions, the experiments which this paper describes were designed. An attempt has been made to conform the experiments as closely to actual practice as possible.

The manufacturers of the sewer pipes most commonly used in New England were consulted, and they most cheerfully co-operated, furnishing to us such pipe as was needed.

The experiments may be divided into two sections; first, those to ascertain the strength of the pipe; second, those to ascertain the pressure created in trenches of varying depth and material by the filling itself and external weights.

In the breaking tests the pipes were laid in a trench exactly as in practice, and the pressure applied by an hydraulic machine to a platform resting on the filling over the pipe.

In the tests of earth pressure the same machine was placed in the bottom of a deep trench, and the earth filled upon a platform resting on the plunger, which communicated the pressure to a gauge.

The tensile and compressive strengths of the pipe material have been studied by breaking briquettes and cubes, made by an inspector at the pipe works, and burned in the same manner as the pipe itself. While of little practical value in themselves, these results may furnish a basis of comparison to other experimenters, and possibly be of some value to the manufacturer.

A very simple hydraulic pressure machine was designed for the experiments. It merely consists of a shell or cylinder of cast-iron with a plunger which rolls in a rubber diaphragm. The shell is cast in two parts, the upper portion having the cylinder-head cast with it; the lower has an open end, and the two parts are bolted together through heavy flanges.

The inside of cylinder and face of plunger flange were roughly machined.

The plunger is a plate one inch thick, strengthened by three webs $\frac{3}{4}''$ x $3''$, crossing at angles of $60°$, with a flange $15''$ deep around the outside, which forms the working surface. The diameter of this plunger is $23\frac{1}{4}''$, or four times the thickness of the rubber diaphragm less than the diameter of the cylinder.

The rubber diaphragm is of common construction in smaller sizes, but unusual in the present size. It was molded using the upper portion of the machine as the female mold and a special iron casting as the male. Two layers of cloth, with heavy coats of rubber on the outside and between them, were used in its construction, the thickness being 3-16 of an inch.

APPARATUS USED IN BREAKING PIPE.

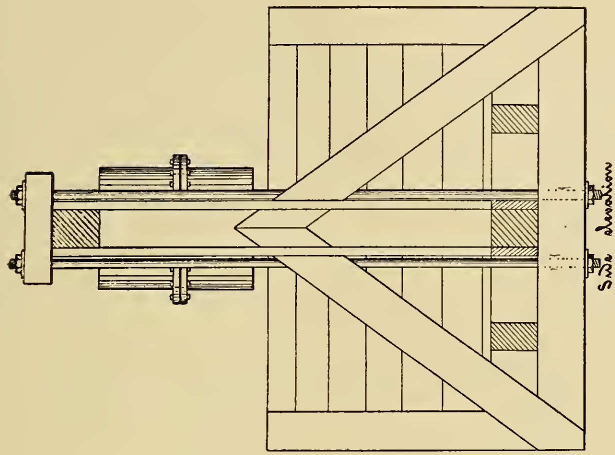


FIG. 1, *b*.

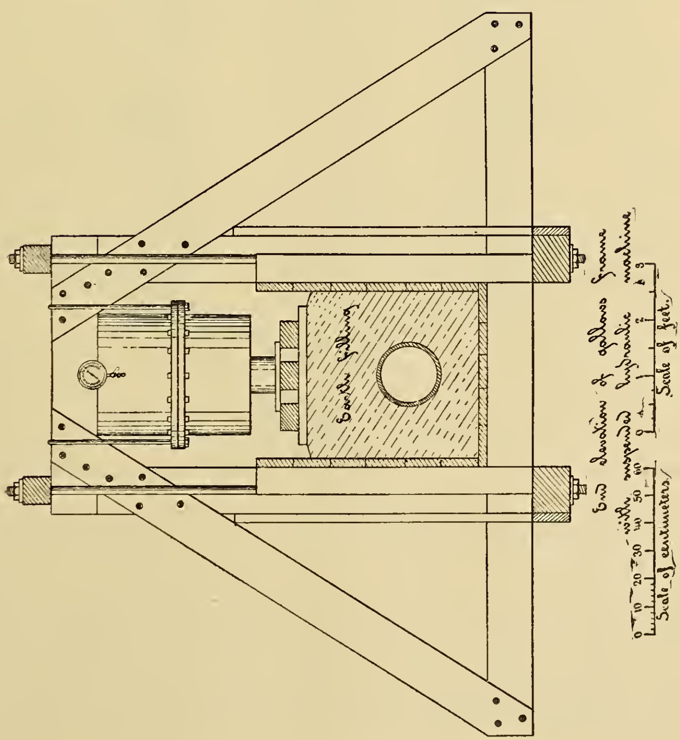


FIG. 1, *a*.

The shape of the diaphragm, as made, is like a round hat with a rim about two inches wide. In the machine the hat is upset and its rim caught between the flanges of the upper and lower sections of the cylinder. The plunger is then pushed up so that it rolls the crown of the hat inwardly, and the double thickness of rubber, being just the distance between the outside of the plunger and the inside of the cylinder, forms a rolling packing, perfectly water-tight, with little friction, and allowing a movement of fifteen inches safely.

The chief merits of the machine were cheapness, owing to the small amount of machine work, and the absence of leakage. The latter virtue was more evident in the experiments of trench pressures, where any leakage, such as would be probable with an ordinary piston, would have made the experiments almost impossible.

Water pressure was obtained from a windmill tank, and where this was insufficient, a small force pump was used.

To reverse the machine, the water was removed by a siphon, the longer leg of which was low enough to create sufficient head to rapidly raise the plunger.

The gallows frame, on which the machine was hung, is well shown in the plan and photographs. It consists essentially of two upright 8″ x 10″ hard pine sticks, mortised into two longitudinal sills of the same size and material, spaced 3.0 feet apart and capped by hard pine of same dimensions. Oblique braces extend from the uprights to the longitudinal sills, and also to a transverse sill. Four 2″ iron rods passing through the sills and maple blocks which crossed the cap, held the frame together. Two-inch planking was nailed to the inside of the uprights and to posts mortised into sills, forming a box 4.0 feet high, 3.0 feet wide and 8.0 feet long. The floor was made by planking, nailed to 6″ x 10″ floor beams spanning the sills. This box formed the trench in which the pipe to be broken was laid.

In all cases eight inches or more of earth was put in first, then the pipe was laid lengthwise of the trench, directly under the machine, and covered with earth, which was filled in in three-inch layers and thoroughly rammed. The ends of the pipe were sheeted up, a hole being left in the planks at each end to admit a candle for inspection. The sheeting was two inches longer than the pipe, and burlap was loosely stretched to keep the filling from falling down.

When the pipe was covered to the desired depth, a platform made of 2″ plank, held together by three 4″ x 6″ pieces of hard

wood, was placed on top, and to this the pressure of the machine was applied. The platform was always of the same length as the pipe, and thirty inches wide.

The pressure was carried from plunger to platform by a circular maple block eight inches in diameter, which gave a greater bearing surface than a metal rod. This block bore on a metal plate, which crossed the hard wood straps of the platform.

The depth of filling over pipe varied from six to eighteen inches. It was found that the amount of this filling made no difference, provided there was enough over the pipe to allow the

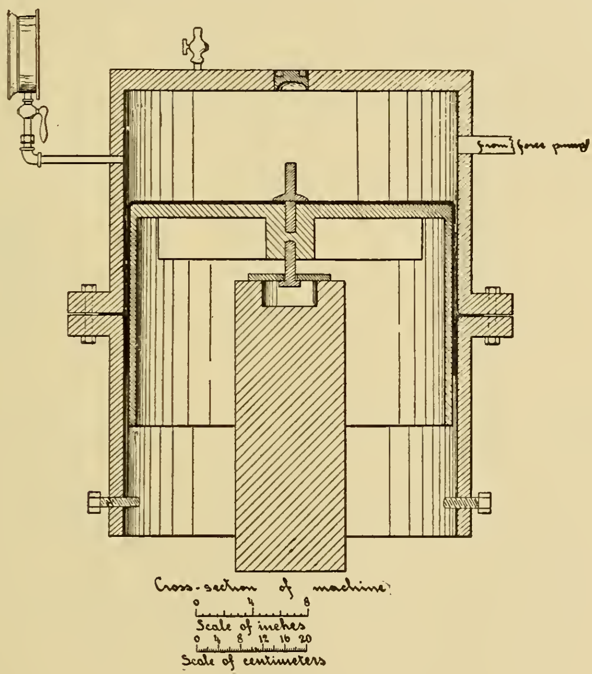


FIG. 1, *c*.

earth on the haunches to compress without bringing the pressure directly on crown of pipe. Six inches was sufficient to permit this.

It could not be assumed that the net effective area of such a plunger was equal to the area of the inside of cylinder, and a series of calibrations were accordingly made to determine this area. These were not all made at the same time, some being the result of a desire to know if the same coefficient of friction held good throughout the experiments, and were made at various times.

The method of calibration was to suspend from the long arm

of a 6″ x 6″ wooden lever a barrel of cement, and to balance by pressure applied to the short arm by the machine. The lever worked on iron rollers resting on iron plates, and all distances were measured accurately with a steel tape, the weight of cement and lever being carefully ascertained.

From readings of a vacuum gauge attached to the machine, taken with plunger ascending and descending, data was obtained from which it was easy to figure that the friction of machine equaled .245 pounds per square inch, and that the weight of the plunger was equal to .6 pounds per square inch. With the surface of plunger 1.2 feet below zero of gauge at moment of reading, a constant of .86 pounds had to be added to gauge reading to express the total pressure on short arm of lever.

The following table gives results of calibrations:

No.	Calculated Area.	Residual.	Square of Residual.
1	423.01	+4.18	17.4724
2	421.07	+2.94	8.6436
3	412.75	—6.08	36.9664
4	414.82	—4.01	16.0801
5	420.77	+1.94	3.7636
6	420.58	+1.75	3.0625
7	418.11	—0.72	.5184
	418.83		

Probable error of mean value = ± .968. According to the method of least squares, this result is .968 inches greater or less than the true value. From notes taken at the time of calibration, it is believed that observations 3 and 4, owing to variation in the height of plunger at the time of reading gauge, and the consequent change in the constant to be added to gauge reading, are too low, and the area—for the sake of even figures—will be called 420 square inches. This will be within a small fraction of one per cent. of the true value.

As it was found to be impracticable to note the height of the plunger in all the pipe breaks at the moment of reading gauge, and as the average breaking pressure was about 40 pounds, and the gauge could only be read to one-quarter of a pound, it is evident that the error in calibration of plunger is well within the limits of error of the other factors.

It is evidently needless to carry accuracy any further than the least unit to be determined by observation admits of, and the probable result of all errors is less than one per cent.

Table 2 shows the complete log of results. The first column gives the size and brand, whether A or B, *d* indicating

double strength; the second gives the number of specimen broken; the third the time of applying pressure; the fourth the length of pipe without bell; the fifth the thickness in inches, so far as measured, and the sixth the gauge pressure in pounds.

Table 3, in the first seven columns, shows the averages of the preceding log of results. The eighth column, which gives the total load on the platform, is obtained by multiplying the net area of plunger, in square inches, by the gauge pressure, with the constant .8 pounds added (as explained above).

Dividing this total load by the length of pipe (as given in column 5 + .25 foot for the bell) gives the load per linear foot of platform, as shown in column 9. Column 10 gives the load per linear foot of pipe (figured as equal to internal diameter in width); thus, the platform being thirty inches wide, the load per linear foot of a 15″ pipe is just one-half that of the platform. Column 11 gives the load per square foot of platform—obtained by dividing column 9 by 2.5 feet (the width of platform). Column 12 gives the percentage which the minimum breaking load is of the average breaking load.

Columns 10 and 11 express the results of most interest and value; column 10, showing strength per square foot, forms the means of comparing pipe strength with earth pressure, which will be considered further on in this paper.

Column 9 is of interest to pipe manufacturers and engineers as an expression of the actual ability of the several sizes to carry loads applied over the span of the arch; that is, of the strength of the different sizes per span, and not per square foot.

An examination of this column shows the breaking load per linear foot to average about 2800 pounds for the standard pipe and 4200 for the double strength. The uniformity of the figures of this column has led to an attempt to express in formula the relation of thickness of pipe to the cracking strength per linear foot, for it is to be remembered that all these figures refer to cracking and not destruction of the pipe.

It has been found that the strength per linear foot varies inversely as the diameter and directly as a function of the thickness, which is very near the power whose index is 1.65. This is expressed by the following formula:

$$p = c\,\frac{t^{1.65}}{d} \quad \text{or} \quad t = \sqrt[1.65]{\frac{pd}{c}}$$

when p = pressure per linear foot in pounds; t = thickness in inches; d = diameter in inches, and c a constant equal to 33,000.

TABLE 2. SHOWING LOG OF RESULTS OF PIPE BREAKAGES.

Size and Brand.	Number of Test.	Time of applying Pressure, Minutes.	Length, Feet and Inches.	Thickness, Inches.	Gauge Pressure, Pounds.	Size and Brand.	Number of Test.	Time of applying Pressure, Minutes.	Length, Feet and Inches.	Thickness, Inches.	Gauge Pressure, Pounds.	Size and Brand.	Number of Test.	Time of applying Pressure, Minutes.	Length, Feet and Inches.	Thickness, Inches.	Gauge Pressure, Pounds.
6″-A.	1	9	2′.00″	.70	49.25	8″-A.	31	5	3′.00″	.82	91.75	12″-A.	61	3	3′.00″	1.04	51.25
	2	9	"	.70	61.75		32	5	"	.82	77.50		62	3	"	1.04	51.00
	3	4	"	.73	77.00		33	6	"	.83	86.25		63	3	"	1.07	70.00
	4	7	"	.73	74.25	8″-B.	34		2′.00″	.82	41.00		64	5	"	1.05	57.00
	5	5	"	.72	67.75		35	8	"	.82	52.00		65	4	"	1.05	55.25
	6	4	"	.72	79.00		36	7	"	.82	69.00		66	5	"	1.06	74.00
	7	5	"	.73	83.00		37	8	"	.82	36.00	12″-A. (*d*)	67	4	3′.00″	1.26	64.50
	8	5	"	.74	61.75		38	7	"	.82	61.00		68	4	"	1.26	81.00
	9	4	"	.72	63.00		39	6	"	.82	62.00		69	3	"	1.26	69.00
6″-B.	10	7	2′.00″	.66	65.00		40	7	"		52.00		70	4	"	1.26	84.25
	11	5	"	.66	74.25		41	5	"		61.00		71	6	"	1.26	75.00
	12	5	"	.70	69.00		42	5	"		71.00		72	5	"	1.26	76.00
	13	5	"	.66	56.00		43	5	"		49.00	12″-B.	73	5	2′.00″	1.00	42.50
	14	8	"	.66	95.25		44		"		65.50		74	6	"	1.02	57.50
	15	7	"	.66	70.50	10″-B.	45	7	2′.00″	.80	53.75		75	5	"	1.00	44.00
	16	5	"	.66	58.25		46	6	"	.85	63.50		76	5	"	1.00	41.50
	17	5	"	.66	56.00		47	5	"		65.50		77	5	"	1.00	41.50
	18	5	"	.66	63.50		48	5	"		66.50		78	5	"	1.00	35.00
	19	5	"	.68	79.50		49	4	"		49.00	15″-A.	79	2	3′.00″	1.24	42.00
	20	5	"	.70	86.25		50	5	"	.83	65.00		80	3	"	1.24	62.50
	21	5	"	.66	70.25		51	3	"		32.00		81	4	"	1.24	52.25
	22	4	2′.00″	.68	64.00		52	3	"	.84	48.00		82	4	"	1.24	54.50
8″ A.	23	5	"	.78	25.25		53	5	"	.84	67.50		83	4	"	1.22	48.00
	24	7	"	.78	25.00		54	5	"		47.50		84	4	"	1.22	55.00
	25	6	"	.78	34.75		55	6	"		42.00	15″-A. (*d*)	85	6	3′.00″	1.46	85.50
	26	7	"	.78	35.50	12″-A.	56	6	2′.00″	1.00	24.00		86	5	"	1.46	75.00
	27	7	"	.78	35.25		57	5	"	1.04	24.75		87	5	"	1.44	65.50
	28	6	"	.78	39.75		58	5	"	1.00	23.75		88	5	"	1.44	71.00
	29	4	3′.00″	.82	72.25		59	4	"	1.00	22.25		89	4	"	1.44	63.50
	30	6	"	.82	98.00		60	5	"	1.04	28.75	15″-B.	90	4	2′.00″	1.08	28.25

TABLE 2. SHOWING LOG OF RESULTS OF PIPE BREAKAGES—*Continued.*

Size and Brand.	Number of Test.	Time of applying Pressure, Minutes.	Length, Feet and Inches.	Thickness, Inches.	Gauge Pressure, Pounds.	Size and Brand.	Number of Test.	Time of applying Pressure, Minutes.	Length, Feet and Inches.	Thickness, Inches.	Gauge Pressure, Pounds.	Size and Brand.	Number of Test.	Time of applying Pressure, Minutes.	Length, Feet and Inches.	Thickness, Inches.	Gauge Pressure Pounds.
15″-B.	91	4	2′.00″	1.12	34.25	18″-B.	121	5	2′.00″		23.00	20″-B.	151	4	2′.00″		19.25
	92	4	"	1.15	33.00		122	5	"		20.25		152	4	"	1.28	18.75
	93	4	"	1.15	29.00		123		"	1.22	21.75	20″-B. (*d*)	153	4	2′.00″	1.76	18.75
15″-B. (*d*)	94	6	2′.00″	1.36	59.00		124	5	"		18.00		154	5	"		28.50
	95	4	"	1.36	39.00	18″-B. (*d*)	125	6	2′.00″	1.53	38.50		155	5	"		26.75
	96	5	"	1.36	58.50		126		"		36.00		156	3	"		23.00
	97	5	"	1.36	42.00		127	6	"		36.00	24″-A.	157	3	2′.00″	1.47	14.50
	98	4	"	1.38	41.50		128	5	"	1.52	33.75		158	3	"	1.48	15.00
	99	4	"	1.36	39.00		129	5	"	1.52	37.25		159	4	"	1.48	12.25
18″-A.	100	5	2.′00″	1.46	25.25		130	2	"	1.52	39.50		160	3	"	1.48	12.75
	101	5	"	1.44	30.50	20″-A.	131	4	2′.6″	1.29	26.75		161	4	"	1.48	14.00
	102	5	"	1.40	18.75		132	6	"	1.29	27.75		162		"	1.48	20.50
	103	5	"	1.40	17.25		133	3	"	1.29	26.75	24″-A.	163	4	2′.6″	1.46	22.00
	104	5	"	1.42	21.25		134	3	"	1.30	23.75		164	4	"	1.46	22.50
	105	2	"	1.44	30.75	20″-A. (*d*)	135	5	2′.6″	1.70	30.75		165	4	"	1.46	23.75
	106	6	3.′00″	1.26	31.75		136	6	"	1.72	46.25		166	4	"	1.46	23.25
	107	5	"	1.26	31.00		137	5	"	1.72	46.00		167	5	"	1.46	24.75
	108	5	"	1.26	31.75		138	6	"	1.72	30.00	24″-A. (*d*)	168	6	2′.6″	2.02	36 00
18″-A. (*d*)	109	7	3′.00″	1.54	56.00		139	5	"	1.72	39.00		169	5	"	2.02	34.00
	110	8	"	1.54	55.00		140	5	"	1.72	46.00		170	4	"	2.02	34.00
	111	4	"	1.54	58.75	20″-B.	141	3	2′.00″	1.32	14.75	24″-B.	171	1	2′.00″	1.48	11.75
	112		"	1.54	40.25		142	3	"		16.00		172	1	"	1.48	13.50
	113	3	"	1.56	49.00		143	3	"		14.25		173	2	"		14.00
18″-B.	114	5	2′.00″	1.17	31.25		144		"		16.75		174	2	"		12.00
	115	4	"	1.16	30.75		145		"		20.75		175	1	"		13.00
	116	4	"		21.50		146	3	"		28.00		176	2	"		14.25
	117	4	"		26.50		147	4	"	1.34	21.24		177	3	"		19.00
	118	5	"		22.50		148	4	"	1.30	17.25		178	2	"		15.00
	119	4	"	1.16	20.00		149	4	"	1.34	18.00		179	4	"	1.47	17.00
	120	5	"	1.16	27.50		150	3	"		18.25		180	4	"	1.49	21.75

Table 3. Showing Averages and Principal Results of Breakages.

Size of Pipe.	Brand.	Number of Pieces Broken.	Time of applying Pressure.	Length without Bell.	Thickness, Inches.	Gauge Pressure, Pounds.	Total Load on Platform, Pounds.	Load per Linear Foot of Platform, Pounds.	Load per Linear Foot of Pipe, Pounds.	Load per Square Foot of Platform, Pounds.	Percentage of Minimum Break.
						STANDARD.					
6″	A	9	5.8	2′.00″	.72	68.55	29127	12945	2589	5178	72
6″	B	13	5.5	2′.00″	.67	69.87	29681	13191	2638	5276	80
8″	A	6	6.6	2′.00″	.78	32.58	14020	6232	1662	2493	76
		5	5.5	3′.00″	.822	85.15	36099	11108	2962	4443	85
8″	B	11	6.5	2′.00″	.821	56.32	23990	10662	2843	4265	64
10″	B	11	5.1	2′.00″	.832	54.56	23251	10334	3445	4134	60
12″	A	5	5.0	2′.00″	1.02	24.70	10710	4760	1904	1904	90
		6	3.8	3′.00″	1.05	59.83	25465	7836	3134	3134	85
12″	B	6	5.2	2′.00″	1.00	43.66	18673	8299	3319	3319	80
15″	A	6	3.4	3′.00″	1.23	52.37	22331	6871	3435	2748	80
15″	B	4	3.9	2′.00″	1.13	31.12	13406	5958	2979	2383	90
18″	A	6	4.5	2′.00″	1.43	23.96	10399	4618	2771	1847	72
		3	5.5	3′.00″	1.26	31.50	13566	4174	2504	1670	98
18″	B	11	4.6	2′.00″	1.18	23.91	10378	4612	2768	1844	80
20″	A	4	4.1	2′.6″	1.29	26.25	11361	4131	2754	1652	77
20″	B	12	3.5	2′.00″	1.32	18.60	8148	3621	2414	1448	77
24″	A	6	3.4	2′.00″	1.48	14.83	6564	2917	2334	1167	82
		5	4.2	2′.6″	1.46	23.25	10101	3673	2938	1469	95
24″	B	10	2.1	2′.00″	1.48	15.12	6686	2972	2377	1188	78
						DOUBLE STRENGTH.					
12″	A	6	4.4	3′.00″	1.26	74.96	31819	9790	3916	3916	86
15″	A	5	4.9	3′.00″	1.45	72.10	30618	9421	4710	3768	88
15″	B	6	4.7	2′.00″	1.36	46.50	19866	8829	4414	3531	84
18″	A	5	5.6	3′.00″	1.56	51.80	22092	6796	4077	2718	77
18″	B	6	4.8	2′.00″	1.52	36.83	15804	7024	4216	2809	92
20″	A	6	5.4	2′.6″	1 72	39.66	16993	6179	4119	2472	75
20″	B	4	4.2	2′.00″	1.76	24.25	10521	4676	3117	1870	77
24″	A	3	5.0	2′.6″	2.02	34.67	14897	5417	4334	2167	97

Table 4 shows the size, thickness and strength as found by the experiments, and strength as given by the formula of the standard and double-strength pipe, the figures being in general the average of results of brands A and B.

In the 10″ pipe only Tests 54 and 55 were taken. The laborer had, in the other 10″ breaks, been leaving in the earth under the pipes and forming a kind of cradle, instead of removing it entirely between breaks. This was the only case of the kind, and the change from the usual conditions seemed to justify the throwing out of all the 10″ tests except Nos. 54 and 55.

In the 12″ the A 2-foot lengths were also thrown out in striking the average for this size.

TABLE 4.

Standard.				Double Strength.		
Size.	Thickness.	Strength by experiment.	Strength by formula.	Thickness.	Strength by experiment.	Strength by formula.
6″	.695	2613	3015			
8	.822	2902	2985			
10	.832	2834	2440			
12	1.024	3226	2862	1.26	3916	4028
15	1.18	3207	2890	1.405	4562	3855
18	1.29	2681	2790	1.54	4146	3738
20	1.305	2584	2560	1.74	4119	4113
24	1.47	2549	2598	2.02	4334	4382

Such discrepancies as are noticeable are believed to be caused by the natural variations in the burning of the clay, and it is thought that a more extended series of tests would show the result tending still nearer those of the formula.

Fig. 2 shows this formula expressed graphically for the different sizes of pipe, the ordinates being the thickness in inches, and the abscissæ the breaking load per linear foot, with the corresponding breaking loads per square foot for the different sizes added at the top of the sheet.

An examination of this diagram will show that sewer pipe, as made at present, is not of such relative thickness as to give the same strength in the different sizes.

Engineers may reasonably demand that standard pipe have a breaking load of 3000 pounds, and double strength 4500 pounds per linear foot, in all sizes.

It is fully realized that with the same strength per linear foot, a 6″ pipe is four times as strong per square foot as a 24″, and that therefore a uniformity, per linear foot, means little, so far as bear-

Breaking Loads Per Square Foot for Different Sizes.

6″ pipe	4000	5000	6000	7000	8000	9000	10000	11000	12000
8″ "	3000	3750	4500	5250	6000	6750	7500	8250	9000
10″ "	2400	3000	3600	4200	4800	5400	6000	6600	7200
12″ "	2000	2500	3000	3500	4000	4500	5000	5500	6000
15″ "	1600	2000	2400	2800	3200	3600	4000	4400	4800
18″ "	1333	1667	2000	2333	2667	3000	3333	3667	4000
20″ "	1200	1500	1800	2100	2400	2700	3000	3300	3600
24″ "	1000	1250	1500	1750	2000	2250	2500	2750	3000

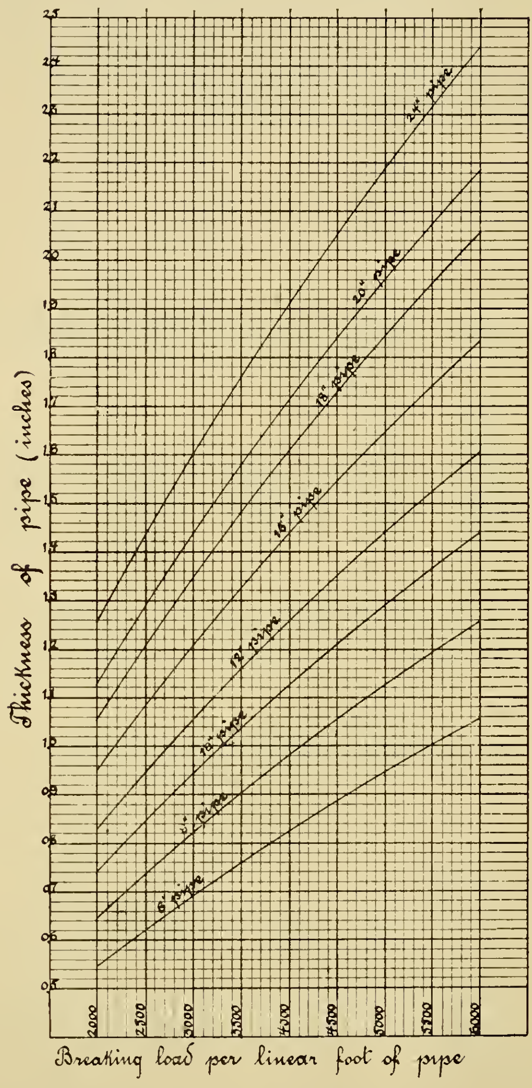


FIG. 2.

Relation between thickness and strength in vitrified clay pipe, calculated from the following formula:

$$p = c\frac{t^{1.65}}{d} \text{ or } t = \sqrt[1.65]{\frac{pd}{c}}$$

p = pressure per linear foot; t = thickness in inches; d = diameter in inches; c = consonant = 33000. Tensile strength of clay = 900 pounds per square inch. Compressive strength of clay = 6500 pounds per square inch.

ing strength goes. But in order to obtain the same strength per square foot, a 6″ would either have to be too thin, or a 24″ too heavy to handle, and for the sake of uniformity the unit per linear foot is recommended.

Whether future investigation will prove that the above formula expresses a relation between thickness and strength of pipe that will hold good generally, cannot be known except from experience. It represents fairly well the results of the pipe breakages described in this paper; and as the present thickness of the different sizes of pipe are not apportioned according to any rule, it is offered as an expression of the general case.

To obtain the recommended uniform strength per linear foot, of 3000 pounds for standard and 4500 pounds for double thick pipe, according to this formula, 10″, 18″, 20″ and 24″ standard will have to be increased to .94, 1.348, 1.437 and 1.605 inches respectively; and 12″, 15″, 18″ and 20″ double thick to 1.35, 1.543, 1.73 and 1.84 inches respectively, the other sizes being of the proper thickness at present.

Having a pipe of this known bearing strength, its factor of safety depends on the trench pressures, which leads us to that portion of the experiments.

The trench experiments, as before stated, were designed to ascertain the pressure created on a pipe, culvert, brick sewer or other structure built in a trench, by the superincumbent earth.

Common sense tells us that this pressure is not a multiple of the weight of earth per foot by the depth, but rather some fraction of this product depending on the nature of the material. To ascertain this net pressure in trenches the hydraulic machine, before described, was placed on two sills laid lengthwise in the bottom of a 13-foot trench, the cylinder being inverted and filled with water, which kept the plunger about the center of its movement. Everything being water-tight, there was no need of any pump, the water merely upheld the plunger and communicated the weight to the gauge.

On the plunger a block of pine, 18″ in diameter and 15″ high, was placed. On this, two 6″ x 4″ sticks rested and carried the platform, 5′-2″ long by 3′-3″ wide, on which the earth was filled. The machine and platform reduced the depth of trench available for experiment to 8.8 feet, which is the maximum depth of filling that was weighed.

The ends of the trench were in all cases sheeted, enough of the front sheeting being removed to permit reading of the gauge. The sides, likewise, to a point three inches higher than the platform,

were always sheeted, forming with the ends a permanent box in which the platform worked. A space of one inch was left in all cases between sheeting and edge of platform. To prevent the earth from falling through this crack to the machine below, burlap was loosely tacked to the platform and sheeting.

Above the level of the platform the sides were sheeted or not, as the conditions of the different experiments demanded. It is to be noted that while the sides were not sheeted in some cases, the ends were always sheeted. No rangers or braces were used on the inside of end sheeting, so that the recorded pressures must be higher, or on the safety side therefore, in every case, than in a continuous trench.

The first experiment was made with unsheeted sides, sloping from a bottom width of 4.0 feet to 6.0 feet at a height of 9.0 feet. The material used for filling was the loam as found at the Filter Beds, sandy, but damp enough to retain shape when pressed in the hand. It weighed 96 pounds per cubic foot.

The second experiment was made in same kind of a trench as the first, but the filling was in this case sand and gravel. This material would, according to the standard of the State Board of Health, have an effective size of .6 mm, not counting the stones which ranged from size of a pea to an egg, with perhaps two of the latter in each shovelful. The sand was sharp, and weighed 115 pounds per cubic foot. In the third experiment the sides were sheeted vertically and smooth, all rangers and ties being kept on the outside. The material used in filling in this and all the other tests, except No. 1, was the sand and gravel as just described.

The fourth experiment was made with sides sheeted on a slope of $\frac{1}{4}$–1, the width increasing from 3.8 feet at the bottom to 7.8 feet at the top.

In the fifth experiment the trench was dug out to a width of 8 feet at the level of the platform, the sides being vertical and unsheeted. The platform thus occupied 39 per cent. of the area of the bottom of trench.

The sixth and last experiment was made by once more sheeting the sides vertically, but instead of leaving the sheeting smooth, as in experiment 3, pieces of boards and plank were nailed to the sheeting in various ways to increase friction.

In these experiments one man backfilled while another rammed the material in the trench, the filling being made in six-inch layers, and readings of the gauge taken at the completion of each layer.

Table 5 gives, in the first column, the depth of filling measured

TABLE 5. SHOWING RESULTS OF TRENCH EXPERIMENTS.

First Experiment.			Second Experiment.			Third Experiment.		
Depth of Filling.	Net gauge Pressure	Ratio of gauge load to weight of earth, per cent.	Depth of Filling.	Net gauge Pressure.	Ratio of gauge to load weight of earth, per cent.	Depth of Filling.	Net gauge Pressure.	Ratio of gauge load to weight of earth, per cent.
1.2	4.15	82.2	.5	2.25	89.3	1.0	3.55	68.6
1.8	5.25	69.6	1.05	4.15	78.4	1.5	5.60	72.3
2.3	6.00	62.2	1.6	5.65	70.1	2.0	6.75	65.2
3.0	6.75	53.0	2.1	6.95	65.9	2.5	7.55	60.4
3.5	7.25	48.3	2.5	7.75	61.4	3.0	8.35	53.1
4.0	7.65	44.2	3.0	8.35	54.7	3.5	9.80	53.2
4.5	8.15	41.4	3.5	8.95	49.7	4.0	10.75	50.5
5.0	8.80	39.8	4.0	9.95	47.9	4.5	11.95	49.4
5.5	9.40	38.5	4.5	10.75	45.6	5.0	13.05	48.3
6.0	9.95	37.2	5.0	11.75	44.5	5.5	14.25	47.6
6.5	10.65	36.6	5.5	12.65	43.3	6.0	15.55	47.4
7.0	11.20	35.6	6.0	13.35	41.7	6.5	16.75	46.9
7.5	11.90	35.2	6.5	14.95	42.2	7.0	18.05	46.7
8.0	12.40	34.3	7.0	15.65	41.6	7.5	18.95	45.6
8.8	13.35	33.5	7.5	16.60	40.9	8.0	20.25	45.6
			8.0	17.55	40.5	8.8	21.75	44.4
			8.8	18.65	39.0			
Fourth Experiment.			Fifth Experiment.			Sixth Experiment.		
.5	.70		1.0	3.50	69.5	.5	1.15	45.6
1.0	3.65	70.5	1.5	5.05	66.8	1.0	3.65	72.5
1.5	5.65	72.1	2.0	6.05	60.2	1.5	5.55	73.4
2.0	7.00	67.6	2.5	7.25	57.4	2.0	6.45	64.2
2.5	7.85	62.8	3.0	8.05	52.7	2.5	7.45	59.0
3.0	8.95	56.9	3.5	8.85	49.2	3.0	8.25	54.0
3.5	9.85	53.4	4.0	9.95	47.9	3.5	9.15	50.8
4.0	11.15	52.4	4.5	10.60	44.9	4.0	9.75	46.9
4.5	12 75	52.8	5.0	11.65	44.1	4.5	10.55	44.7
5.0	14.35	53.0	5.5	12.65	43.3	5.0	11.25	42.6
5.5	16.15	53.9	6.0	13.95	43.6	5.5	12.25	41.9
6.0	17.75	54.1	6.5	14.55	41.7	6.0	13.20	41.2
6.5	19.25	53.7	7.0	16.65	44.2	6.5	14.05	40.3
7.0	20.75	53.9	7.5	17.75	43.8	7.0	14.65	38.9
7.5	22.35	53.9	8.0	18.65	43.0	7.5	15.45	38.1
8.0	23.75	53.5	8.8	19.25	40.3	8.0	16.25	37.4
8.8	26.05	53.2				8.8	17.45	36.5

from top of platform; in second column the net gauge pressure, and in the third column the percentage which total load by gauge is of weight of filling vertically over platform. This last column has been expressed gıaphically in Fig. 3.

Experiments 1 and 2 were intended as a study of sloping unsheeted sides, the first filled with loam, the second with gravel.

Looking at the curves on Fig. 3, it is seen that in experiment 1 the percentage of weight of superimposed earth, transmitted to platform ranged from 76 per cent., with a depth of filling of 1.5 feet, to 33 per cent., with 9 feet; and in experiment 4 from 72 per cent. to 39 per cent. at these same depths, the curves crossing at about a depth of two feet. In the higher depths the greater

cohesion of the loam absorbs about 6 per cent. of the weight of earth.

Proceeding to experiment 3, these percentages ranged from 72.0, with 1.5 feet filling, to 44.0, with 9.0 feet filling. It thus appears that the sheeting of the sides causes 5 per cent. increase in the pressure transmitted to platform.

Considering next experiment 6,—trench sheeted as in experiment 3, but rough instead of smooth,—it is found that with the same depths these percentages range from 73.5 to 36.0.

Experiment 5 may be compared with experiment 2, the first made by digging out the trench to a width of 8 feet with vertical sides, the second with sides sloping from the width of platform at bottom to a width of 6 feet at top. Both were gravel filled and unsheeted on sides. Experiment 5 was made particularly to ascertain the net pressure on platform when it occupied only a portion of the bottom of the trench. The net pressure, as shown by curve, varies from 67.0 per cent., at 1.5 feet, to 40.0 per cent., at 9 feet, results very similar to those of experiment No. 2. This indicates that the pressure per square foot on *unsheeted* trenches is about the same whether vertical or sloped, and that there is no wedging effect from sloped sides, a pipe having to carry a load proportioned to its horizontal surface.

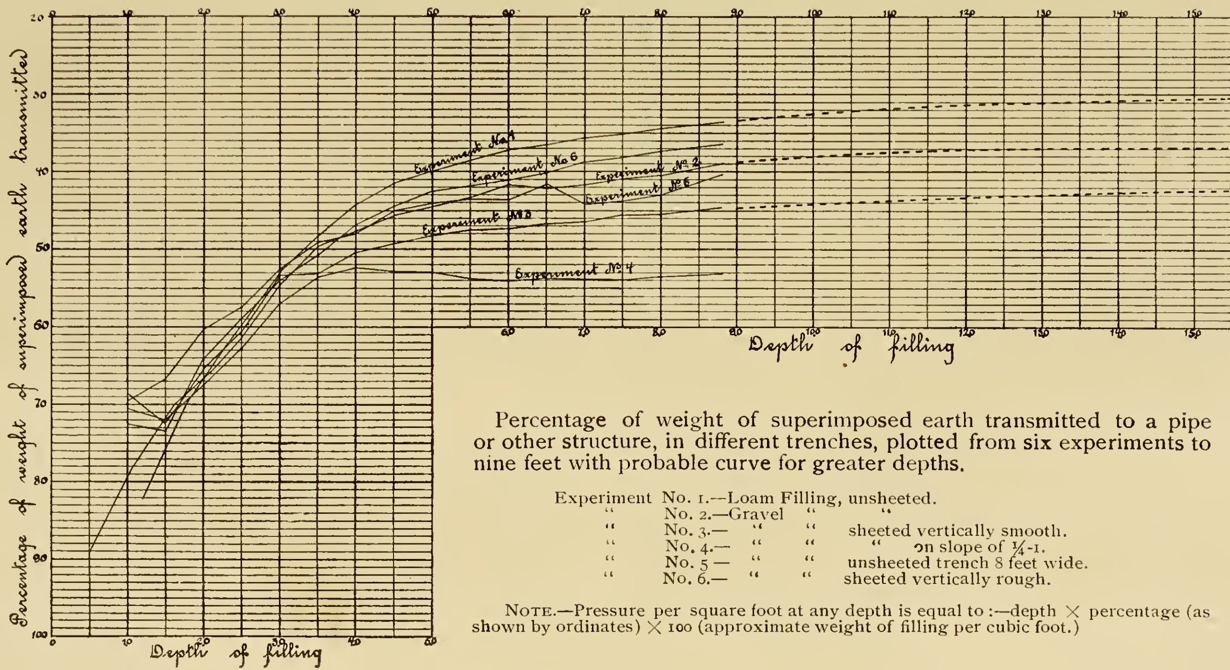
The fourth experiment, with sheeted sides sloped $\frac{1}{4}$–1, was made to study the wedging effect in such a trench. It is seen from the curve that the percentage of weight of superimposed earth transmitted to platform ranged from 72.0 per cent., at 1.5 feet, to 53.0 per cent., at 9.0 feet, being much higher than in the other experiments.

Looking over Fig. 3, the small difference in the results of the several experiments is very striking. Leaving out experiment No. 4 as an exceptional case, it is seen that the difference in net pressure is less than 10 per cent.

These results cover well all trench conditions *except the very important one of variation in the nature of the filling material.* The curves show that it is not the friction of the sides, but rather the cohesion of the particles of earth filling which determines the net pressure on the pipe. Experiment No. 5 seems to indicate that the width of trench, within limits, has little influence on this result.

Friction is a function of the pressure perpendicular to surface acted on, or in this case cohesion is a function of the lateral earth-pressure, and the relation of lateral pressure to weight of earth depends on the fluidity of material.

An examination of the diagram shows the cohesion rapidly increasing to a depth of about 5 feet, at which point the curves take



Percentage of weight of superimposed earth transmitted to a pipe or other structure, in different trenches, plotted from six experiments to nine feet with probable curve for greater depths.

Experiment No. 1.—Loam Filling, unsheeted.
" No. 2.—Gravel " "
" No. 3.— " " sheeted vertically smooth.
" No. 4.— " " " on slope of ¼-1.
" No. 5 — " " unsheeted trench 8 feet wide.
" No. 6.— " " sheeted vertically rough.

NOTE.—Pressure per square foot at any depth is equal to :—depth × percentage (as shown by ordinates) × 100 (approximate weight of filling per cubic foot.)

FIG. 3.

a more horizontal direction. As an explanation of this curve it may be offered, that up to a certain depth the rapidly increasing ratio of lateral pressure to weight of earth, and at the same time the rapidly increasing coefficient of friction, owing to lessened fluidity of material under pressure, together act to increase cohesion, or, in other words, lessen percentage transmitted to pipe. At the point where the earth filling becomes almost further incompressible, the coefficient of cohesion becomes constant and the curve approaches a horizontal straight line.

It will be noticed that in curves of experiments No. 1 and No. 2, the loam and gravel unsheeted trenches, that when the straight line is reached the percentage transmitted to pipe is about 31.0 and 36.0. These figures are equal to the difference between the coefficient of friction of loam and gravel, and unity. If we may extend this relation to other materials, we have a means of estimating the percentage of pressure transmitted by the more dangerous materials.

On this assumption it may be said that after the ratio of lateral pressure to weight has reached a constant which will be at depths about 10 feet, the percentage of weight of filling (or of external weights) transmitted to a buried structure will be the difference between unity and the tangent of angle of repose of the material in trench.

A wet clay with coefficient of friction equal to .35 will, on this basis, transmit 65 per cent. of its weight to a buried structure, and this may be considered the extreme case.

So far as the curves are based on experiment they are undeniably correct. It was rather a surprise to the writer to find that a 6″ layer of earth transmits its own percentage of pressure through 9 feet of filling which had been thoroughly rammed in 6″ layers, but such was the case, and we see no reason why this rule should not hold within any practical limits.

After completing the filling of the trench in experiment No. 2, thirty granite blocks, weighing 3750 pounds, were piled up on an area 2.0 x 3.35 feet. The gauge pressure was increased 2.05 pounds, or 23.5 per cent. of the actual weight of the stones was transmitted through 9 feet of gravel to the platform.

Repeating this on the trench with smooth sheeted vertical sides, 30.9 per cent. of weight of stones was indicated by increased gauge pressure. With rough sheeted sides 32.0 per cent. was transmitted to platform, and with trench 8 feet wide, as in experiment 5, only 19 per cent.

The net pressure is therefore invariably a smaller percentage

of weight of external object than that indicated by the diagram of net pressure of filling, and it will be well within the limits of safety to use the diagram in figuring net weight of external objects at different depths.

Accepting, then, these curves as of some value, and assuming the weight of earth as 100 pounds per cubic foot, it is only necessary to multiply the depth by ordinate of curve to find the net pressure per square foot at different depths.

Referring to Table 3, column 11, we find the breaking load per square foot of the several sizes of pipe as found by experiment, or, better, let us assume that all standard pipe are to be made of such a thickness as will carry an ultimate load of 3000 pounds, and double strength a load of 4500 pounds. Compare these figures with the results of the trench experiments and we have an expression of the ability of sewer pipe to stand probable pressure.

Table 6 is an attempt to express the factor of safety afforded by the different sizes of pipe, standard and double strength, up to a depth of 20 feet in a gravel trench. Column 1 shows the depth; column 2 the net pressure transmitted, as shown by experiment 2; column 3 the net pressure from road roller and filling at the different depths, and the other columns the factor of safety found by dividing the ultimate breaking load of the several sizes, as given at head of column by the figures of column 2.

From a careful study of the preceding table and a comparison of the results there indicated with such actual failures of sewer pipe as we have been able to investigate, 3 has been chosen as the necessary factor of safety.

Referring to Table 3, it is found that the average minimum breaking load is about 80 per cent. of the average breaking load. Therefore a factor of safety of 3, based on the average breaking load, is only equal to a factor of 2.5 based on the minimum breaking load.

The ultimate breaking loads of the pipes upon which the preceding table is based were obtained from pipe thoroughly well laid in an unyielding trench. The net pressures were, it is true, obtained from new trenches, and are probably much greater than in an old trench, but it is to be noticed that the figures are based on weight of filling alone, no live load being taken into account.

Take the extreme case of a road roller weighing fifteen tons, with perhaps six tons on each of the six-foot rear wheels, which are eighteen inches wide. With a surface depression of 6 inches, this means a load of about 2500 pounds per square foot over an area 1.5 x 3.3 feet, or much the same as the granite blocks covered.

TABLE 6. SHOWING RELATION OF STRENGTH OF PIPE TO PRESSURES IN TRENCH. EXPRESSED AS FACTOR OF SAFETY.

Depth of Trench feet.	Net pressure of earth. Lbs. per sq. ft.	Net pressure of earth and steam roller. Lbs. per sq. ft.	Factor of Safety. 6″	8″	10″	12″		15″		18″		20″		24″	
			Standard	Standard	Standard	Standard	Double Strength.	Standard	Double Strength.	Standard	Double Strength.	Standard	Double Strength.	Standard	Double Strength.
			6000	4500	3600	3000	4500	2400	3600	2000	3000	1800	2700	1500	2250
1	80	2080	75.0	56.2	45.0	37.5	56.2	30.0	45.0	25.0	37.5	22.5	33.8	18.7	28.1
2	130	1755	46.2	37.6	27.7	23.1	37.6	18.4	27.7	15.4	23.1	13.8	20.8	11.5	18.8
3	165	1540	36.4	27.3	21.8	18.2	27.3	14.5	21.8	12.1	18.2	10.9	16.4	9.1	13.6
4	190	1390	31.6	23.7	18.9	15.8	23.7	12.6	18.9	10.5	15.8	9.9	14.2	7.9	11.8
5	220	1320	27.2	20.4	16.4	13.6	20.4	10.9	16.4	9.1	13.6	8.2	12.3	6.8	10.2
6	250	1300	24.0	18.0	14.4	12.0	18.0	9.6	14.4	8.0	12.0	7.2	10.8	6.0	9.0
7	285	1310	21.1	15.6	12.6	10.5	15.6	8.4	12.6	7.0	10.5	6.3	9.5	5.2	7.8
8	320	1320	18.7	14.1	11.2	9.4	14.1	7.5	11.2	6.2	9.4	5.6	8.4	4.7	7.0
9	350	1325	17.2	12.9	10.3	8.6	12.9	6.9	10.6	5.7	8.6	5.3	7.7	4.3	6.4
10	380	1330	15.6	11.8	9.5	7.9	11.8	6.3	9.5	5.3	7.9	4.7	7.1	3.9	5.9
11	410	1340	14.6	11.0	8.8	7.3	11.0	5.8	8.8	4.9	7.3	4.4	6.6	3.6	5.5
12	440	1350	13.6	10.2	8.2	6.8	10.2	5.5	8.2	4.5	6.8	4.1	6.1	3.4	5.1
13	470	1375	12.8	9.6	7.7	6.4	9.6	5.1	7.7	4.3	6.4	3.8	5.7	3.2	4.8
14	505	1405	11.9	8.9	7.2	5.9	8.9	4.7	7.1	4.0	5.9	3.5	5.3	2.9	4.4
15	540	1435	11.1	8.3	6.7	5.6	8.3	4.4	6.7	3.7	5.6	3.3	5.0	2.8	4.1
16	570	1455	10.5	7.9	6.3	5.3	7.9	4.2	6.3	3.5	5.3	3.1	4.7	2.6	3.9
17	600	1480	10.0	7.5	6.0	5.0	7.5	4.0	6.0	3.3	5.0	3.0	4.5	2.5	3.7
18	630	1505	9.5	7.1	5.7	4.8	7.1	3.8	5.7	3.2	4.8	2.8	4.3	2.4	3.5
19	665	1540	9.0	6.8	5.4	4.5	6.8	3.6	5.4	3.0	4.5	2.7	4.1	2.2	3.3
20	700	1575	8.6	6.4	5.1	4.3	6.4	3.4	5.1	2.9	4.3	2.5	3.9	2.1	3.2

Column 3 gives the total effective load per square foot at the different depths of this live load and the earth filling.

Comparing these figures with the ultimate breaking load at the head of each column, it is seen that in such an extreme case the pipes have a very small factor of safety.

Any factor chosen must cover the variations in strength of pipe and the iniquities of pipe-laying, and it is believed that 3 is a factor of safety small enough to cover such contingencies in the safer trenches of gravel.

In such material as shown on Fig. 3 the percentage of pressure transmitted to pipe is about 35.0. If, as elsewhere discussed, as high as 60 per cent. may be transmitted in the more dangerous materials, in such cases a higher factor, based on this percentage, should be chosen.

Thus, while, according to the table, 20″ standard is safe at a depth of 17 feet in gravel, in wet clay double strength should be used at this depth.

While appreciating the many elements of discord entering into trench work, capable of greatly altering such results as here presented, it is believed that some such basis of judgment may help to decide whether standard or double-strength pipe is necessary, and perhaps form a foundation for future observers on this subject.

Moreover, it is probable that if engineers should decide that the thicker pipe is necessary at certain depths, and increased quantities should be used, its price, which is at present out of all proportion to its cost, as compared with standard pipe, would fall to a level where it could reasonably be used.

SPECIAL RESULTS.

The following table shows the results of breaking special pipe which were marked as soft, medium and hard-burned by the manufacturer:

TABLE 7.

Degrees of Burning.	6 inches.	8 Inches.	12 inches.	15 inches.	18 inches	Average.
Soft....................	61	64	40	51	48	52.8
Medium	65	59	43	29	31	45.4
Hard..................	49	59		38	36	45.5

Only one piece of each degree of burning in each size was broken, so that the results are accordingly not especially trustworthy. So far as shown, however, little can be inferred as to the strength of pipe from the degree of burning. According to the

table, the soft pipe were 15 per cent. stronger than the medium and hard, which broke at about the same figures.

The soft pipe were a light chocolate in color, having a good solid body; not a pipe that would be condemned from its appearance, although lighter than is preferred by many engineers in New England.

The medium pipe were of the average appearance, such as were broken in the general tests, while the hard were of a bluish gray color, brittle and, in the opinion of the writer, overburned.

A careful study of the external color and the texture of the various pipe throughout the tests failed to furnish any satisfactory explanation of the variation in breaking load.

It has been noticed in the shale pipe, that low breaks are often found in laminated pipe—those which on breaking separate in concentric layers. This by no means explains all low breaks, but is an accompaniment of the majority of them. It would seem reasonable that this would be a cause of weakness. The laminations are probably caused by the lagging behind of the clay next to the inside and outside molds, and the forcing of the center clay ahead. Lubrication of the molds might prevent this action.

The noticeably low breaking strength of the 20″ B double-strength pipe is plausibly explained by the appearance, in the middle third of the thickness of the pipe, of a black streak resembling porous slag. While the average body of this pipe absorbed about 1.5 per cent. of its weight of water in 24 hours, this burned portion absorbed 4.5 per cent. in the same time.

It may be due to too quick water-smoking, or driving off of the moisture in the clay. Whatever the cause, it is an object of interest to inspectors, as it makes double strength no stronger than standard pipe.

The pipes usually break in four pieces in straight lines, through the center of the crown and invert and along the springing lines of the arch. When these lines, dividing the pipe into four equal sections, are not followed it is usually found that the crack is determined by a fire-crack or small stone. Thorough grinding and mixing of the clay is an important factor in the manufacture of good pipe.

In several cases pipes with fire-cracks several inches long have been placed in the trench so that the crack came half-way between the points of probable breakage, and the pipe stood the average pressure, breaking as usual into four parts.

Fire-cracks are undoubtedly an element of danger; and if the pipe is used it should be placed as described.

Attention has been already called to the fact that the breaking loads, as recorded in this paper, refer only to the cracking of the pipes, and not to their destruction.

In several cases attempts have been made to crush the pipes to destruction, but always without success. The gauge pressure was run up to over 100 pounds on 8″, 10″ and 24″ pipe, and, although the cracks at invert and crown opened $\frac{1}{4}$″, it was evident that the pipes would stand much more before destruction.

It may be said that with a good incompressible foundation a 24″ pipe, with sides and haunches thoroughly tamped, after being cracked, will stand a pressure of 10,000 pounds per square foot without collapsing.

This leads to a consideration of the value of concrete around pipes. It evidently merely serves as a good, unmovable foundation, and when this can be obtained with the material in the trench, concrete half-way up a pipe adds little strength. Where concrete in a bad trench is filled in solid between sheeting which is to be left in, the case is different. Several pieces of 8″ pipe were laid in concrete—4″ under pipe and 6″ on sides to half diameter of pipe. The pipes broke at 65 pounds gauge pressure, or 16 per cent. greater than the average ultimate breaking load of pipes in earth.

In an attempted study of the conditions under which breakages have occurred in practice, letters were written to all the places in New England where it was known that there had been failures. The sizes which have failed have usually been 18″ in diameter and upwards of standard pipe, but in three cases double-strength pipe has failed.

Except in one place, where pipe known to be of inferior quality was laid, the depth of cut has been from sixteen to twenty feet.

In almost all cases there is a reasonable cause of the failure in the conditions or methods of construction. Leverage of chimneys, unstable foundation, unequal settlement at manholes, washing of foundation into open joints of underdrains, are some of the reasons given for the failure of pipes.

All of these are causes beyond the ability of the pipe manufacturer to meet, causes which the engineer by proper care can overcome. In order to do this with any reasonable surety of result, the pipe should have a uniform strength to withstand pressure by proper proportioning of the thickness to the several diameters, and greater care on the part of the pipe manufacturers to study the determining conditions in burning.

To the uninitiated, clay burning, in its lower forms, appears a

most unscientific proceeding. Temperatures are judged by the eye, and necessary length of burning by specimens placed where they may not represent anything like the average burning of the kiln. The kilns are usually in the hands of an autocrat whose knowledge of the art is his capital, which he carefully keeps to himself.

It would seem as if the pyrometer, with electric transmission and the coal calorimeter might be used with advantage to put the knowledge of kiln burning on some more rational basis. It may be that the meteorological conditions are too potent a factor to permit any refinements; at any rate there is a great variation in the strength of pipe to-day, as witnessed by the low break of 8″ and 12″ A pipe, and considerable loss to the manufacturer from culling.

To sum up the principal results of this paper: Pipes of all sizes have been laid in trenches, covered with earth, and broken by pressure applied to a platform resting on filling, these conditions being as nearly like those of actual practice as it is possible to attain.

As the result of these breakages, a relation between thickness of pipe and strength has been expressed, and it is suggested that all pipe be made of uniform strength by properly proportioning the thickness to diameter—standard pipe to have a strength of 3000, and double strength 4500 pounds per linear foot when laid and covered with earth, so that the pipe is supported by well-tamped filling.

From experiments made in trenches with gravel and loam filling, the actual pressure at different depths has been ascertained and expressed as a percentage of the weight of earth superimposed. This percentage rapidly decreases with increasing depth, until at about 10 feet or less it reaches a constant value. This value, in the case of loam and gravel,—the two materials experimented upon,—was found to be equal to the difference between unity and the coefficient of friction of these materials.

If this relation may be extended to other materials, a means is afforded of estimating the actual earth pressures in trenches of all materials of which the coefficient of friction or angles of repose are known.

Comparing this actual earth pressure with the breaking strength of pipe per square foot, factors of safety for the different sizes of pipe at different depths are figured, and it is suggested from a study of known pipe failures in practice that 3 be provisionally chosen as the necessary factor of safety in gravel trenches, with an increased factor, based on angle of repose, for other

material. In this way a means of more readily deciding whether double-thick pipe or concrete is necessary will be afforded, and whether experience bears out its value or not it will at least form a foundation about which to group future judgments and results.

In connection with the breaking tests, an attempt has been made to determine the form of pipe joint which, while fulfilling practical requirements, would give the minimum leakage.

Special pipes 8″ in diameter were made, with joints varying from ½″ to 3″ deep and from ¼″ to 1″ thick.

Over two hundred sets were made up and tested in the same manner as described by Mr. Freeman C. Coffin, in his paper on "Tests of Cement Joints for Sewer Pipe."

The assistant who made these tests was at first instructed to pack the cement into the joints with a wooden caulking tool, the mortar being of the consistency of dry mud. It was soon found that in this way almost any joint could be made so that, under a five-foot head, it would not leak enough to measure in three hours, and this has been considered as water-tight. No comparison of the efficiency of the different joints could be thus obtained, and accordingly the mortar was made more moist and the joint formed, as in practice, by a trowel and gloves.

The results have been decidedly unsatisfactory from the standpoint of a written report, and no tabulations of the figures will be given. It is believed, however, that in this irregularity, perhaps, information of value may be found.

All the work has been done by an assistant who knew nothing of the probable results, and who was instructed to treat each joint alike as to tamping and filling.

Tests of the time of setting and tensile strength of the cement were carried on at the same time, and proved the cement to be high grade.

The several joints experimented upon were as follows, the first figure indicating depth, the second width: ½″ x ½″, ¾″ x ½″, 1½″ x ⅜″, 2″ x ½″, 2½″ x ½″, 3″ x ½″. For comparison the joints were made of neat cement, and not overfilled.

No very high leakage was obtained from any form of joint, the average being about 2500 gallons per mile; the lowest 850 gallons, with the ¾″ x ½″; the highest 14,500 gallons, with the 1–½″ x ⅜″ joint.

In the six-hour tests the Rosendale neat leaked 70 per cent. more than the Portland, the average of all joints being 3245 for Rosendale and 1900 gallons per mile for Portland.

In the eighteen hours tests, however, the difference is the other

way, the Portland leaking 10 per cent. more than the Rosendale, the figures being 1650 and 1485 gallons per mile, respectively. This is probably due to the slower set of the Rosendale, which only leaked 45 per cent. as much after an eighteen-hour set as after a six-hour set, while the Portland eighteen-hour leakage is 85 per cent. of the six-hour leakage.

The most noticeable result is the small leakage in the shallow joints, $\frac{1}{2}''$ and $\frac{3}{4}''$ deep. An examination of the cement removed in taking the joints apart, however, plausibly explains this result. In the shallow joint the cement is perfectly hard and compact for the entire depth, bonding well with the irregularities of the pipe, while in the joint $3''$ x $\frac{1}{2}''$ only the upper portion is usually solid, the cement beneath being porous and full of air-spaces. This was obtained in joints which had been packed with trowel until the water flushed well to the surface. The clinging of the cement to the sides makes it difficult to thoroughly fill a depth greater than $1\frac{1}{2}''$ unless the width is proportionally increased, or efforts out of all comparison with actual practice are made.

The above results indicate that experimentally a joint $\frac{3}{4}''$ deep is as water-tight as one $3''$ deep made with the same effort. Of course, in practice the difficulty of keeping green cement from falling out of a shallow joint makes the minimum depth of joint greater than this.

It is not believed that the best depth is capable of experimental proof. The results which have been obtained showed comparatively little difference in the leakage of joints varying from $\frac{1}{2}''$ to $3''$ deep, except in the very narrow $\frac{3}{8}''$ joint, where it was six times as great as the average of the joints $\frac{1}{2}''$ wide. Leakage depends upon the depth of the surface hardening of the cement, and it is reasonable that unless the deeper joints are thoroughly compacted they should leak as much as the shallow joints. With the very narrow joint, however, not even the upper $\frac{1}{2}''$ was thoroughly filled. By "filled" is here meant absence of air-holes, however minute, because water, under a five-foot head, easily forces its way through such openings.

The effect of overfilling was tried with the $\frac{1}{2}''$ x $\frac{1}{2}''$ joint and the advantages shown, the leakage being only 220 gallons per mile, or about 10 per cent. of the leakage through this joint without overfilling.

In the tests of mortar joints with 1 cement to 1 sand and 1 cement to 2 sand, the leakage differed but little from the neat joints, except that in this case the deep $3''$ x $\frac{1}{2}''$ joint leaked much less than the shallow joints. It is reasonable that, so long as the

percentage of cement is sufficient to fill the voids of the sand, the leakage through the mortar made of clean, sharp sand and cement should differ little from that through neat cement.

In conclusion, it is believed that the following results have been indicated by the tests:

First. That experimentally a tight joint, under a five-foot head, can be made by using dry mortar and sufficient tamping.

Second. That from joints made more nearly as in practice little information can be obtained.

Third. That all joints should be overfilled.

Fourth. That joints less than $\frac{1}{2}''$ wide cannot be made tight without undue labor.

Fifth. That the difference between Rosendale and Portland cement joints is slight after an eighteen-hour set.

Sixth. That an overfilled shallow joint is as tight as a deeper joint, unless great care, such as is seldom taken in practice, is used to fill the deeper joint.

The deeper joint, however, better resists the dangers of pipe movement before set of cement and the injury from backfilling, and this consideration makes a joint deeper than one inch at least necessary. How deep it should be is a mere matter of judgment. The personal equation of the pipe layer and the inevitable disturbing elements of trench work render it of little use to figure that the leakage is affected by changes of fractions of an inch.

For the sake of the manufacturers, and indirectly of the consumers of sewer pipe, it would be well if some standard dimensions of pipe joints could be decided upon.

It is believed that a joint $2'' \times \frac{1}{2}''$ for pipes up to $12''$ in diameter, and $3'' \times \frac{5}{8}''$ for larger sizes, will, when overfilled, give as good results as can be obtained.

DISCUSSION.

Mr. F. Herbert Snow.—The city of Brockton was one of the first places to use the deep socket pipe designed by the late M. M. Tidd and put on the market by the Portland Stone Ware Company. We were satisfied that it was an improvement, and planned on purchasing more at the first opportunity.

It so happened, however, that the lowest bidders for furnishing the first large lot of pipe were the Akron manufacturers, who did not make deep socket at that time. I insisted that this kind of pipe should be furnished, and the local representative of the Akron people—being determined to secure the contract—induced one of the Commissioners and myself to go to Akron, make our

wants known, and prevail upon the manufacturers to accede to our request.

It was stated at the conference that the Eastern engineers were not only very particular, but also not agreed, regarding the proper depth of bell and width of socket, and that it was impracticable for the manufacturers to attempt to cater to the whims of every engineer. They finally agreed, however, to make what we wanted, and at least two of the factories went to the expense of getting out a new set of dies.

Later, the experiments of Mr. Freeman C. Coffin proved to us that we had done right in insisting on deep socket.

The experiments which we have conducted in Brockton seem to prove the standard socket to be preferable. I am of the opinion, however, that a satisfactory demonstration of this question by experiments in the laboratory alone is impracticable, because of the difference between the conditions under which the experiments must be conducted in the laboratory and those encountered by actual experience in the trenches.

We are not prepared to-day to alone take a definite stand regarding the proper dimensions of bell and width of socket.

There is as great a difference of opinion among Eastern engineers on the subject now as there was three years ago, and it would seem desirable that the matter be taken up and an attempt be made to reach an agreement between ourselves and the manufacturers.

Regarding the object of the experiments: On several occasions, early in the construction of the sewerage system, we had some doubt whether to use the old standard or the new double-strength pipe. A thorough discussion of the question did not remove the doubts. I explained the uncertainties of the matter to the Sewerage Commissioners, who looked into the question, and—wishing to conduct this public work as they did their private business, by eliminating all uncertainties so far as practicable, and believing that the cost of making certain experiments would be money well invested, since the results obtained might be of practical value to the city in the purchase as well as the use of the pipe—I was finally authorized and directed to proceed, and the paper which Mr. Barbour has read to you to-night has been made possible by these two years of experiments.

The manufacturers of the pipe mostly used in New England cheerfully coöperated from the first, putting themselves to expense and trouble, and we have carried the tests along with the hope that the results obtained might be an aid to some more

definite and satisfactory conclusion among engineers regarding the strength and dimensions of pipe.

I trust that this Society will manifest an active interest in the subject, and that finally the Sewerage Commissioners and the manufacturers may see the practical results of the money invested in the experiments.

Mr. T. Howard Barnes.—I am very glad that Mr. Snow has put this matter on the basis that he has,—viz, facts presented for discussion. Although I had the benefit of an advance copy, I have not had time to do very much in the way of food for thought in this discussion.

I think there are many points of interest covered by his experiments, and there are some questions that arise in my mind along the line of theories. First and foremost, as a demonstration, may be mentioned the extreme satisfaction that may be felt in thinking that, although the pipe may crack, if it is well packed around it will not break down; that is, it will possibly affect the leakage, but we do not have the mortification of digging that pipe out, and that is oftentimes the principle which may be adopted in cases where the presence of an occasional cracked pipe does not seriously affect our work. Those of us who have systems in the Metropolitan Sewerage District cannot do that, however, for the item of possible leakage both in and out is inadmissible.

There is one of the theories that come up as to the question of back-filling: what the effect would be of a pressure on the pipe in a very moist earth, consisting mostly of clay, which condition often occurs after a fall of rain or by puddling. It seems doubtful in my mind if the rule will hold which has been suggested.

Certainly, such a condition is liable to make a very much greater pressure on the pipe; but another question is, whether or no the pressure exerted will not be further lessened *in its effects* by the greater lateral pressure communicated. The fact that the ends of the trench are sheeted up in the experiments would seem to modify the deductions. In practice there would be no sheeting there, and the earth filling would transmit an applied stress back and forth over a more extended area.

It is human nature to be satisfied with conclusions which correspond with your own, and in that respect I am rather pleased with Mr. Barbour's conclusions in regard to joints and form of socket.

I had felt for some time that the shape in respect to the depth of socket was not enough; that, indeed, the depth was not the

principal item, but that we needed more width, and, more than all, we needed that whatever depth we had should be filled. That is the secret of tight sewers. It is the *"getting done"* of what we specify.

I took out a section of 8-inch pipe which shows a depth of socket of only 1¾ inches. The width is nearly ½ inch at the mouth, and there is a slight flare, something like 15°. This specimen shows that the cement reached the bottom of the socket only in places. This was supposed to have been laid under very careful inspection.

I feel that the Society's thanks are due to the city of Brockton, Mr. Snow and Mr. Barbour for their very important results, for these facts presented to us, and that we may follow them up, as Mr. Snow has suggested, and make the most of them.

Mr. Henry Manley.—I do not desire to discuss the absolute merits of these experiments, as the subject is not in my special line of engineering; but I have had occasion to do some work that has a bearing upon it—a very heavy bearing, so to speak. We build in Boston a good many "assessment" streets, so-called, generally in the open country and for the benefit of the owners of the adjacent lands, who pay the entire expense. In these streets, under the law, the sewers, gas pipes and water pipes, with house connections for each house and vacant lot, must be in place before the street is surfaced. Consequently, I have had considerable experience in running steam rollers over recently filled trenches containing sewer pipes. This has been going on for seven years, and I do not at this moment recall an instance where the steam roller has injured a house sewer pipe.

In many of these streets there is an entirely separate and additional system of surface drains, which are laid at a much shallower depth, and in a few instances the steam roller has smashed those pipes, but in every such case it has been where there was a great depth of soft mud underneath the filling, and where the pipes were laid at a very shallow depth. Frequently they come within 18 inches of the subgrade, which is rolled with the steam roller, and the back-filling is often badly rammed and oftener not rammed at all. One of the chief uses of the road roller is to search out these badly filled trenches, and to allow the upper layers of the back-filling to be sufficiently consolidated to carry the roadway surfacing.

As I say, in seven years, covering a large amount of this kind of work, I do not recollect more than six or eight crosslines of drain pipe that have been broken.

In deeper sewers—brick sewers on piling, for instance, on soft ground—the sewer engineers (which, I would have noted, are an entirely separate body, that being a branch of the Street Department proper,) were apprehensive, in some cases, that the sewers would be injured by the roller.

It has long since been noted that the effect of the steam roller in consolidating material extends but a very short distance. When an excavation beyond a foot or two below the surface is made, no effect of the steam roller can be found, and on that account I was of the opinion that the roller would not be likely to damage the sewers. In one particular case, where there was a large-sized brick sewer, there was a considerable argument between the two kinds of engineers, and it was finally agreed that the sewer engineers should enter and place across the sewer a large number of struts—something like laths—that would be flexible, and that during the progress of the rolling they should be watched, and if any signs of movement occurred the work should be stopped. The street was rolled and the sewer was not injured. Since that time no precautions have been taken, except in cases where there is a very thin cover over the sewers, and no sewers have been injured, so far as is known.

Mr. J. A. Baldwin, of the Buckeye and Summit Sewer Pipe Companies, Akron, Ohio.—I am not accustomed to speaking in meetings. We are here by your kindness to see what we can learn, and learn what we can, as to your demands. We realize that, directly and indirectly, you are our largest customers, and as business men it is our interest to please you, to cater to your wishes as far as practicable, and keep in line with you. Perfect pipe are as scarce as perfect men. We know of three qualities in pipe that you all demand, and in these we strive to excel: First, to give you pipe of strength to carry any weight liable to be thrown upon it; second, an internal surface that will give the least possible friction, free from roughness or excrescences that will catch fibrous matter or obstruct the flow of sewer matter; and, third, a body absolutely impervious to the action of any matter that finds its way into sewers. In these respects we do our best to merit your favor. As to the depth of socket and space for cement, we were making such as we thought would give the best satisfaction to the largest number, but have made changes to cater to the demands of different engineers, and, by the paper read before us, we judge all are not now of one mind. As to what is falsely called double-strength pipe, we think the name misleading, as you only claim for it one-half added strength, and, from

the information we have, we think none will advise the thicker pipe for sizes smaller than 18-inch.

If not intruding, I would like to ask if, in your judgment, the few failures reported when pipe failed perfectly to carry the weight upon it, the failures would have occurred had greater care been used in laying; in short, whether the failures should not be charged to the careless neglect or iniquities of contractor or workman rather than to us manufacturers? As to demanding that the thickness of pipe be proportionate to the diameter, we feel it would without benefit add to the weight of small pipe and cause useless waste in making, in freight and handling. A variation of about one-sixteenth of an inch should be calculated in the thickness of the shell, because of the wearing of dies, and this in small pipe is very perceptible and material. The criticism of our pipe-burners seems hardly just. To burn successfully, one needs long practice and careful observation, watching not only the fires, but its effect upon the pipe while under fire; it is hard, faithful work twelve hours of the twenty-four.

I thank you for the privilege of the evening.

Mr. E. B. Winslow, of the Portland Stone Ware Company, Portland, Me.—It certainly has been a pleasure for a manufacturer of sewer pipe to meet here to-night with the Boston Society of Civil Engineers, and Mr. Barbour's paper certainly was very interesting.

There are a great many things about it that I might perhaps take up and discuss, but I will take but a few minutes. There are a few things I would like to touch upon, although I would prefer to sit still and hear Mr. Snow and Mr. Barnes and the other gentlemen talk upon this question of sewer pipe and the requirements of the engineers, rather than to attempt to impart any information to you myself.

I have never yet had an opportunity to have the engineers, either in a body or individually, visit our works that I have not derived some benefit from it. They always make some suggestions, and while in their specifications there may be some things that are difficult to meet, and there might possibly be some which we would not be successful in meeting, yet I have always made it a rule to satisfy the demands of the engineers. It has been in the past looked upon, when a contract was let and the specifications were submitted to the manufacturer, that it would be impossible for him to meet the requirements of that specification. I never have known it to fail, after the contract was awarded and the engineer had an opportunity to come to the factory, and if

he had not before had an opportunity to see sewer pipe made he would see at that time wherein it was difficult to meet some of the requirements of his specifications, and would modify them so that it would not be a hardship to the manufacturer.

We looked upon the inspector, in the past, when we started in with the rated inspection of pipe, as if that was a hard thing. I have outlived that. It has educated not only the proprietor of the works, but it has educated every man within the works, to the importance of making goods just as perfect as they can be made. There is not a man, I venture to say, working in the large sewer pipe manufactories of the country, where this inspection is carried on, who does not understand what it means when he is performing his part of the labor; that that pipe has got to go through a rigid inspection, and the man for whom he is working will be the loser if that pipe does not pass the inspection, and in that respect it has done a great deal toward affecting the quality of the sewer pipe put upon the market to-day.

In regard to the testing of pipe, Mr. Barbour's paper to-night is certainly very interesting, and, from a scientific point of view, is the first time I have had the matter called to my attention; but it is not the first time the manufacturer has had it tested underground, and sometimes it has not been just as he would like to have it. I have found, however, in a great many of those cases—I will not say always—what was lacking was an engineer. To illustrate: My attention was called to some pipe that had failed. I visited that place to see what was the trouble. I found the trench had been dug and had continually caved until, when they had the trench large enough for 24-inch pipe, it was some 10 feet wide at the top. They had put the hose on and had flooded the whole body. It is not necessary for me to tell you what weight must have been there after the water had run on it all day and all night.

Another case where I called attention to the party laying pipe, claiming that they were not back-filling as they should do, I was informed that they proposed to do it with a steam roller, and they did it, and the result was that the pipe did not stand the test.

The failure of the pipe is not always the fault of the pipe. Sometimes a failure occurs under the care of the engineer, but most of the cases are such as I have spoken to you about to-night.

Another point, which Mr. Baldwin has answered as well as I could possibly answer, is in regard to the burner. In the olden times it was customary to have one burner, and what Mr. Barbour

stated to you is practically true—that the kilns were usually in the hands of an autocrat, whose knowledge of the art was his capital, which he carefully kept to himself, and if he were taken sick it was necessary to shut down until he got well. But it is not the fact to-day. I think any large sewer pipe manufacturer would hardly dare be caught with one burner on hand. It is not an uncommon thing to have quite a number of men about the works that can burn a kiln and finish successfully.

The point was raised in regard to regulating the fire in the kiln other than by the eye and judgment of the burner. There are some questions arise that might possibly make it difficult to do that. You have all visited the sewer pipe works and seen the large kilns. The drafts are not always alike. The kiln will get hotter on one side than on the other, and it is the eye of the burner that generally regulates that by careful watching, repeatedly opening the kiln and slacking the fire. I am not sure, however, but that something of that kind will come about, but it does not seem to me, at this moment, as though it was hardly practicable.

In regard to the strength of pipes and sockets, Mr. Snow has stated to you the experience of manufacturers of socket pipe. A few years ago, Mr. Tidd called my attention to the matter of deep socket pipes, asking me if it were possible to make it, and I said that we were willing to try it and see if it was not practicable to make it. We had dies made, and found we could make it successfully, but it is a difficult pipe to make. We have explained that to many of you who have visited our works, and no doubt the Western manufacturers have explained it. It is a great deal more difficult than it would seem, but I never regretted having made deep and wide socket pipe. Before our friends in the West were willing to take up the manufacture of that pipe we made quite a good many miles of it, and furnished it to the New England cities, and are willing to be given an opportunity to continue the work. The question arose about the time we were well under way. (We had a combination—you all know what that is—but we have not got it now.) We had a combination, and there was one of our New England cities that advertised for deep and wide socket pipe. Then the question arose with the manufacturers of sewer pipe, as there was no regulation as to what the depth and cement space in the standard pipes should be, What constituted a deep and wide socket pipe? They commenced then to make a standard pipe that was about half-way between the deep and wide socket and the old standard pipe. That is the pipe that is being manufactured by most of the pipe manufacturers to-day.

Mr. Barbour touched upon the question of the price of double-strength pipe. I shall have to differ with Mr. Barbour there. I do not think the price is too high in proportion to the standard. The standard is not high enough, and the double-strength pipe is not a very easy pipe to make. It would take some time, and I would rather explain that to you personally, the difficulty in making a double-strength pipe. There does not appear to be any great difference between the standard and the double-strength pipe that would cause any inconvenience to the manufacturer, but it exists. We manufacture and sell all our pipe in New England, and we are catering to the needs of the New England trade. We are only too pleased to make and furnish double-strength pipe, but the price is not too high.

There are, as I said, other points in the paper which I might touch upon. What you people are aiming after is the improvement, if possible, of the sewer pipe which you people have to have to construct your sewers. I want to impress upon your minds that if it was really necessary to make a change to meet the views of the engineers in regard to the pipe, I do not know but what we should have to do it; but it is a large expense when you take the dies only. It means not $100 only, but a good many hundred dollars, to discard the dies and make any radical change in the shape of the socket.

Mr. President, I have occupied, I have no doubt, more time than should be allowed me, but I do want to say this: It is a great pleasure and privilege you have given me to come and meet so many of the engineers of New England, and if it is ever convenient for you to do so, I want to state to you that our works are always open to your inspection, and any suggestions that come from the engineers, I assure you, are appreciated by our company, and we extend to you all a cordial welcome to our works whenever you may find an opportunity to make it convenient to visit us.

Mr. B. W. Robinson, of Akron, Ohio.—I thank you kindly for the invitation to speak to you, but I do not know that I could add much to what has been said. I have been very much interested in the paper read, and, as has been said, we manufacturers want to keep in touch with the engineers and make the pipe best suited for the purposes for which it is used. The experiments of Mr. Snow in the line of deep and wide sockets are very important, as it has been the opinion of the manufacturers that that idea was a fallacy and practice would prove it undesirable. Deep socket pipe has given the manufacturers more annoyance than any other

idea that has come up. One engineer would specify 3-inch sockets, and another engineer would go ½-inch better, and another would perhaps specify 4-inch, thinking it was a good thing, and he would have more of it. Each specification requires a new set of dies throughout, which cost from $500 upward, and you can readily see that our shop would soon be filled with expensive dies and our stock of pipe would contain sockets of various depths. I think these experiments should not be lost sight of, and that we should derive some good from them by uniting on specifications which would be acceptable to both engineers and manufacturers as standard. It seems to me that it would be mutually profitable if the engineers and manufacturers would cultivate a closer relationship by more frequent meetings and exchange of ideas on the subjects in which we are each interested. I thank the Society for the opportunity it has given me of listening to the remarks this evening.

Mr. E. M. Buel, of the National Sewer Pipe Company, Barberton, Ohio.—I came here to-night prepared to make a very good speech and to instruct you in the manufacture of sewer pipe, but, being the last one called upon, I am very sorry to say that my friends and competitors have taken all my speech and left me nothing to say.

The manufacture of double-strength pipe has not been touched upon very thoroughly. Mr. Winslow spoke of it as being difficult to make. There is no question but what he is right. Double-strength pipe, in the first place, must be thoroughly dry before it is placed in the kilns, and even then it must be burned very slowly and evenly. I think we might liken the burning (or baking, as it ought to be more properly called) of sewer pipe to the baking of bread. You can put it into the kilns and bake it hurriedly; the outside will be burned to a crisp and the inside will be dough. I think very likely that the pipe of which Mr. Barbour speaks was, in the first place, put in the kiln before it was thoroughly dried, and, in the second place, was not thoroughly or properly baked.

You are all aware that 24-inch double-strength pipe should be 2 inches thick, but some engineers are calling for this pipe 1¾ inches thick. We are now supplying a large contract for pipe of that thickness. Some engineers call for a pipe with a socket 3 inches deep, some 3½ inches deep, some 2½ inches, and so on, also calling for different thicknesses. As this question is one of vital importance to the manufacturer, I deem it of much importance that the engineers agree upon a certain standard, and, of course,

it would be advisable if they could agree upon a standard that will not require dies different from some that we now have. Of course, every factory is making, and has been making, pipe of so many different styles of sockets and so many thicknesses that they have got a varied assortment on hand. The matter of dies is an important one, as it takes considerable money to equip a factory with various dies necessary for the manufacture of different kinds of pipe.

The Western engineers are copying after their Eastern brethren to a certain extent, and what the Eastern engineers adopt the Western engineers, sooner or later, adopt. If you, gentlemen, could adopt Mr. Barbour's suggestion and settle on certain specifications, it would soon be done throughout the country, and the manufacturers could discard many of their old dies and make pipe of one length, one thickness and one depth of socket. In this way we could carry more of a stock of the different sizes on hand, and it would benefit the trade as well as the manufacturer, as at present there are so many different specifications out that to carry a sufficient stock of each kind would entail the tying up of too much capital. As far as our factory is concerned, we are at all times ready and willing to make any pipe that the engineers want, but pardon me if I suggest that I think the engineers should give us some little encouragement and some little protection. You want the best pipe that is made, and if a few of us go to the trouble to perfect our mode of manufacture and the expense of obtaining new dies for you, do you not think it but just and fair that we be allowed a little more money for our pipe, so that we can use more pains and inspect our pipe closer? If you could shut off some of the manufacturers whose pipe you would not use any way from coming in and knocking down our prices, we believe we could see our way clear to giving you better goods than we are now attempting to give you. I beg to state that our factory is open to the inspection of engineers at all times, and we should be pleased to see each and every one of you there. I beg to thank you for your attention and for the privilege of addressing you.

Mr. Freeman C. Coffin.—I have found Mr. Barbour's paper very interesting. The experiments seem to have been very carefully made and clearly described. They will undoubtedly prove a valuable addition to our knowledge of this subject. One of his conclusions, however, does not appear to me to be sustained by the experiments.

In speaking of the effect of the sheeting at the ends of his

experimental trench, Mr. Barbour said: "As no ranges or braces were used on the inside of the end sheeting, the recorded pressures must in every case be higher than those in a continuous trench, and therefore on the side of safety." In the third experiment described, or the one having the sides sheeted vertically and smooth on the inside, the percentage of pressure on the platform was from 68.6 per cent. with 1 foot of filling to 44.4 per cent. with 8.8 feet. This shows that the friction on smooth vertical sheeting reduces the pressure. In a continuous trench there would be no friction of end sections, and each pipe or section of piping would receive the pressure of the earth above it, undiminished by end friction, but diminished by the friction on the sides.

In the third experiment, where the trench was sheeted on sides and ends, if this sheeting just inclosed the platform, or a space 5 feet 2 inches by 3 feet 3 inches, as seemed to be the case, the area of the side sheeting would be to that of end sheeting in the ratio of about 1.6 to 1. If the effect of the side and end sheeting were equal for equal areas, of the total reduction of pressure, found by the experiments, of 31.4 per cent. to 55.6 per cent., the side sheeting would be responsible for from 19.3 per cent. to 34.2 per cent. and the end sheeting from 12.1 per cent. to 21.4 per cent., or the pressure in a continuous trench would be greater by the amount due to the end sheeting, or from 12 per cent. to 21 per cent. greater than those found in the experiments.

While this may be a wrong interpretation of the experiments, it is probably true that the friction on the end sheeting must have materially modified the pressures, and that those in the actual trench would be a greater percentage of the superimposed load.

Mr. Snow and Mr. Barnes have referred to the deep and wide socket pipe, and both implied that, on the whole, there was no advantage to be derived from the use of such pipe. They referred, I believe, to the experiments and paper of Mr. Barbour as supporting this conclusion.

As I understand the paper, the results of his experiments and his conclusions are decidedly in favor of the deep and wide socket pipe. I do not know just what dimensions are meant by Messrs. Snow and Barnes when they refer to standard and deep socket pipe. Seven or eight years ago, when Mr. M. M. Tidd first suggested deeper and wider sockets, the standard and only pipe an engineer could get for sewers had sockets that were about 1½ inches deep and ¼ inch wide. This often resulted in a cement space not over ⅛ inch thick. Practically entire dependence was placed upon overfilling, with almost the whole of the cement outside of the joint proper.

Mr. Tidd designed a socket, the dimensions of which are given in the following table:

Inside Diameter of Pipe.	Depth of Socket.	Thickness of Joint.
6 inch.	2½ inch.	⅝ inch.
8 "	2½ "	⅝ "
10 "	2½ "	⅝ "
12 "	2½ "	⅝ "
15 "	3 "	⅝ "
18 "	3 "	⅝ "
20 "	3½ "	⅝ "
24 "	4 "	⅝ "

As there was no theoretical basis from which to proceed in designing these joints, and no experimental data upon which to form a theory, it would be remarkable, indeed, if these dimensions should prove to be exactly the most desirable.

It should be noted, however, that the so-called standard sockets of to-day approximate to the above table more nearly than to the sockets of 1890. Mr. Tidd's suggestion has, I believe, accomplished this result.

From a careful reading of Mr. Barbour's description of the experiments on cement joints, and from his conclusions, I believe the following may be gathered:

Tight joints can be made with rather dry mortar, carefully rammed into joints deep and wide enough to admit of such ramming.

In joints as usually made in the trench the mortar is compacted only in the outer ½ inch sufficiently to resist percolation of water under a small head.

In such joints overfilling is desirable, and will reduce the leakage very largely.

No socket should have less than ½ inch of cement space.

In overfilled joints as usually made the shallow joint is as tight as the deeper one, but the latter will better resist the movement of the pipe before the joint is set.

The exact depth of the socket is a matter of judgment.

With the above I entirely agree. I strongly believe, however, that the necessary care should be taken to ram the cement into the joint itself rather than to depend upon overfilling, as there is great danger that the cement outside of the joint will separate slightly from the pipe and leave an open crack directly through the joint.

I have recently made a few joints by putting in the cement

and then ramming a gasket into the outer end of the joint. A joint is readily and easily made in this way: After the pipe is in position, put sufficient mortar in the joint at the bottom of the pipe to nearly fill it. Place the gasket in at this point and ram it in flush with the face of the bell; then fill the joint with cement, from the bottom toward the top, bringing the gasket into place and ramming it flush with the bell, or perhaps a little further in, until finally it is brought up and twisted together at the top and well rammed home. Mortar of almost any consistency can be used in this method. I found that it was easier to manipulate when about as wet as would naturally be used for overfilling joints. If there is an excess of water, the gasket will absorb it and will hold the mortar in place. These joints were broken apart and found to be perfectly filled. They were made with the pipe lying on its side, as in a trench. After the pipe was in position and the mortar mixed, it required from five to six minutes to make a 6-inch joint.

This is certainly the best method that I have ever tried of making a sewer joint. There is very little waste of cement. The gasket will prevent the water from washing out the cement, and greatly strengthen the joint against movement before the cement is set.

For joints made in this way I believe that $\frac{1}{2}$ inch is the best width. The depth of the socket should be about $2\frac{1}{2}$ inches for 6 to 12-inch pipe and 3 inches for larger sizes.

I believe that, in justice to the manufacturers and for the interest of their own clients, engineers should agree upon a table of dimensions. It would be still more desirable that this table be the standard and only table. Some compromise of individual opinion would be necessary.

I believe with Mr. Barbour that $\frac{1}{2}$ inch should be the minimum of width. The matter of depth is not so important. It is probable that some depth between 2 and 3 inches would make a satisfactory socket.

Mr. George C. Dunne.—In order that there may be no misunderstanding in regard to the cement joint in the *standard* and *deep and wide socket* pipes, it should be remembered that, a few years ago, the *standard* pipe allowed only from $\frac{1}{8}$-inch to $\frac{1}{4}$-inch cement joint, and this was all that was required by engineers' specifications.

When the late Mr. Tidd made the drawings for *deep and wide socket* pipe for the Portland Stone Ware Company, he called for $\frac{5}{8}$-inch cement joint on all sizes from 6 inches to 24 inches, in-

clusive. Since then the manufacturers have agreed to change the depth of sockets and cement joint on the *standard* pipe, so that it is now $\frac{5}{8}$ inch on all sizes from 2 inches to 10 inches, inclusive, and $\frac{1}{2}$ inch on the sizes from 12 inches to 24 inches, inclusive.

If I clearly understand Mr. Barbour's interesting address, he believes that it is necessary to have a cement joint of $\frac{1}{2}$ inch on all sizes up to 12 inches, and $\frac{5}{8}$ inch on all the larger sizes. The present *standard* pipe does not meet these specifications, but the *deep and wide socket* pipe does.

Mr. H. P. Eddy, Superintendent of Sewers, Worcester, Mass.—One of your members kindly forwarded me an advance copy of this paper. I have taken a great deal of interest in the matter, not only since I received the copy, but while the experiments were being performed.

Worcester is still using large quantities of cement sewer pipe, together with some of the glazed pipe, and I was very much interested to find out the strength of the cement pipe, in comparison with that of the glazed. Consequently, I asked Mr. Snow to make us a few tests, which he very kindly did. I found that an 8-inch vitrified pipe was about 18 per cent. stronger than the cement pipe; the 10-inch, about 20 per cent.; the 12-inch, about 25 per cent., and the 15-inch, 30 per cent., while in our oval sizes we found that the 14-inch-by-18-inch gave us 2792 pounds as the breaking load per square foot; the 12-inch-by-18-inch, 2750 pounds, and the $12\frac{1}{2}$-inch-by-15-inch, 2033 pounds. The tests are of interest in comparing the strength of the cement with that of the vitrified pipe.

One point which I am rather surprised to find comes out as it does in the experiments—and I am not quite reconciled to it, either—is that the breaking load, or rather what was termed the net pressure in Table 6, should increase from the depth of 6 feet, which appears to be the minimum. Take, for instance, column 3: the net pressure of the earth and the steam roller per square foot is 2080 pounds at 1 foot in depth; at 6 feet, 1300 pounds; while from 6 feet to 20 feet there seems to be a nearly uniform increase. It would seem to me that if the experiments had been carried on a little further and a little deeper than they were the curves shown in Fig. 3 would have run down beyond a fixed point, or at least they would have been simply horizontal lines parallel with each other. I am very much surprised at the increase of pressure beyond the depth of 6 or 8 feet. My own experience is that sewer pipes break nine times out of ten in shallow trenches, and not in the deeper ones. This is true not only of pipe sewers, but

of brick sewers as well. Portions of one line of sewer which would be 6, 7 and 8 feet deep would be cracked, while the same pipe laid further along 9, 10, 12 feet deep, or even deeper, would be in good condition, and I always believed it was on account of the extreme pressure put on the pipe due to the lack of protection from the small amount of material above the pipe.

There is one other point that I want to allude to, because I think that one of your members, Mr. Barnes, of Medford, has rendered a valuable service in suggesting the winding of the pipe joints with cloth. I think I am right in the source of the suggestion. The statement has been made several times to-night that difficulty is experienced with the cement dropping down or being knocked away from the joints before setting, and doubtless the cement shrinks away from the pipe before and during setting. The winding of the joints with strips of cloth immediately after filling with mortar I have tried and found very successful.

I was also very much surprised to find that joints made of Portland cement, after setting 18 hours, leaked more than joints made of Rosendale cement which had set an equal length of time. It would be interesting to know the brand of Portland cement used.

My experience in making joints is that the sand mortar is very much better than neat cement, because there is much less shrinkage. I think that with neat cement there will probably be a shrinking away from the pipes before the cement is thoroughly set, thus greatly increasing the leakage.

Mr. Barbour.—Column 4 of Table 6 was not obtained by experiments. It is merely the result of calculations. The brand of Portland cement used was Alsen.

Mr. Frederick W. Farnham (by letter).—During the period from 1850 to 1870, the lateral sewers and a few of the trunk sewers in the city of Lowell were laid with cement pipe, most of which was made in the city.

From 1870 up to and including the present year, salt-glazed clay pipe or vitrified sewer pipe has been used in the building of all sewers which are of pipe, and all sizes and many different makes have been used, including Scotch pipe (imported), Portland and a half-dozen different brands of Akron pipe. These pipes have been laid at depths from 4 to 24 feet, in every kind of soil and under every circumstance that could possibly arise in a large city, and until 1895 all have been satisfactory.

In 1895, trouble was experienced in certain parts of the city, especially after showers, when the sewers would not carry away

the water delivered into them from the street catch basins. Knowing full well that the sizes and grades were such as would warrant the carrying off of all surface water that might fall upon certain areas, an investigation of the sewers which gave trouble revealed the fact that a 12-inch ring pipe sewer, built in 1878, and a 15-inch bell pipe sewer, built in 1878, had, although carefully laid by experienced city men in the first case and by a contractor in the second case, became so filled with tree roots as to reduce the carrying capacity of said sewers to that of a 2-inch pipe. I am of the opinion that a ring pipe and an ordinary bell pipe can only with great difficulty and exceeding care, under most favorable circumstances, be so laid as to exclude tree roots, and one single spray of root having gained an entrance into the sewer, it is only a question of a short time when the sewer becomes clogged and of no use. Such has been the case in Lowell, and, after mature deliberation and consultation, City Engineer Bowers decided to rebuild the before-mentioned sewers with deep socket pipe, laid with a gasket joint; the joint composed of, first, a layer of cement, then oakum and again cement, the whole made water-tight; and, in fact, during the present year nothing but deep socket pipe has been used, in sizes above 10 inches, and 9188 feet of 12, 15, 18 and 24-inch pipe have been laid. At the time of writing there is being constructed several sewers in close proximity to the City Water Works conduit, which is of brick and from 20 to 40 feet below the surface of the ground. It is imperative to save the conduit harmless from contamination by sewage, and, as the country now being sewered is a thickly settled portion of our city, extra care has been necessary in building sewers. To that end we have used exclusively extra heavy deep socket pipe, laid with a gasket joint, as before mentioned, and the sewers are being laid at a depth of from 9 to 24 feet, and we feel absolutely certain that we are safe, not alone from leakage and infiltration, but also from breakage of 440 feet of 18-inch deep socket, double-thick pipe, laid 24 feet deep in sand excavation over and across said water works conduit.

With these few thoughts and observations favoring deep socket pipe, I will speak of pressures that have come under my observation.

Of the 50 miles of pipe sewers in the city of Lowell, in sizes from 6 to 24 inches and from 18 inches to 24 feet in depth, practically every one has been subjected to pressure from a 15-ton road roller, as well as the constant traffic of heavy corporation teaming, also electric and steam cars, and the first broken sewer

pipe has yet to be found in the city of Lowell. Let me particularize: In 1892, the Lowell and Suburban Street Railway Company erected in the western part of our city a very large power-house and car sheds, built with brick on an extra heavy granite foundation, all of which granite was teamed into Lowell from Chelmsford or Graniteville, and at the time the street railway plant was in process of building a main sewer was being constructed in the street through which all the teaming was done. At a certain place in the street two 15-inch Portland pipes were excavated at a depth of 18 inches from the surface, these 15-inch pipes being a part of a culvert which had previously been laid across the street, and it is a fact that the two pipes excavated were not even cracked, although the average weight per load of stone teamed over them must have been two tons. Since the finding of said pipes at said depth, and subjected to the practical test referred to, we have never doubted the utility of laying vitrified sewer pipe, and at almost any depth. Further, let me say that at depths from 9 to 40 feet, all over the city of Lowell, is found a strata of marl, very fine, and when mixed with water it forms a quicksand difficult to handle, and many times, in laying sewer pipe in this quicksand, we have excavated a few inches below grade and filled in with cinders, upon which pipes were laid, and never have we experienced trouble in so doing. Again, when in said quicksand and unable to get cinders, we have laid a piece of 2-inch plank, 6 or 8 inches wide and 2 feet long, across the trench, and laid pipes upon such ties with satisfactory results. I venture to affirm that in certain sections of our city conditions have existed as difficult to combat as are possible, and they have been met with never a break or a slump, with one exception. In a part of the city known to be the very worst for sewer building or excavation of any nature a 12-inch pipe sewer was to be laid at a depth of $9\frac{1}{2}$ feet. Upon a certain day two pipes were laid before leaving the work for the night, and in the morning neither pipe could be found, not even with a bar. At first we thought of driving piles in the trench, but that meant time and expense, and we finally concluded to use gravel from a bank not far away. Accordingly, teams were loaded with gravel and hauled to the sewer, load after load, until nearly 100 loads were dumped into the trench and went "out of sight;" but "there came a time one day" when the gravel did not disappear, and after a few days' settlement, there being no change, pipes were laid as ordinarily, and all has been well ever since, for 10 years.

I might go on giving illustrations in our experience to prove,

at least to your contributor, that salt-glazed sewer pipe, as manufactured at present, is practical and wonderfully adapted to its principal use, and that *extra heavy* and *deep socket* vitrified sewer pipe fills a long-felt want with the city of Lowell.

Mr. William B. Fuller (by letter).—These experiments, both on the strength of sewer pipe, when subject to pressures similar to those sustained when in actual use, and on the actual pressure transmitted by earth refilled into trenches, enter upon a field in which experimental research has been much needed, and on which there has previously been but little more than theoretical information. The apparatus used serves to indicate to other engineers that very valuable results may be obtained without resort to expensive methods, and each such successful adaptation of means to ends encourages others to devise similar simple apparatus, and, by experimental research on problems of especial interest to themselves, to add to the total of engineering knowledge, and thus make more inexcusable the wastes and risks sometimes observed in construction work.

Mr. Barbour says "the pipe were laid in the trench exactly as in practice." Were there three or four pieces laid and cemented together at the joints as in regular work, and, if so, how long were the joints allowed to set before testing? Was the pressure platform always the exact length of pipe, including bell, and how was the bell situated in relation to the platform? A plan or longitudinal section, showing pipe in place ready for breaking, would make this point clear.

Mr. Barbour presents a formula, $p = c\frac{t^{1.65}}{d}$, which, as he says, represents fairly well the *average* results of the pipe breakages described in his paper, but, as shown in the last column of Table No. 3, it exceeds the minimum breakages of some cases by over 70 per cent., and I am of the opinion that any such formula is of doubtful value, more especially as in this instance it takes a form not sanctioned by theory. If the formula was made up to fit the results given in either Tables Nos. 3 or 4, it must be unreliable, as errors have been made in the makeup of both tables by averaging the first powers of the thicknesses and the corresponding strengths, and in Table 4 the experimental strengths given are averages of averages.

Theory gives to this equation the form $p = \frac{ct^2}{d+c_1 t}$ c and c_1 being constants, and I should hesitate to change this form, unless a careful study of all the conditions of each experiment made it

necessary. In looking over Table No. 2, the great variation in the strength of individual pieces of the same lot is immediately noticed, such variation in some cases, as with the 10″ B, amounting to over 100 per cent. Averages of such widely varying results are apt to be very misleading, unless the conditions of each experiment are identical. Theory indicates, for instance, that the mere packing of the haunches so as to prevent an increase in the horizontal diameter of a pipe under external vertical pressure increases its resistance to cracking more than 100 per cent. Mere variations in tamping alone, therefore, might cause all the variations noted, while the resistance of the pipe material remained constant. Again, the statement that varying the amount of filling over the pipe from 6 to 18 inches made no differences in the pressures transmitted appears to be at variance with the results of the experiments on trench refilling recorded in the second part of the paper, and I should incline to the belief that careful observations would show that varying depths of this filling would produce variations in the recorded pressures. Any variations in burning undoubtedly give widely varying moments of rupture, even in the same lots, and this again would produce varying results. Before suggesting the constant in any formula for thickness, therefore, I should consider it necessary that the conditions—the tamping at the haunches, the percentages of the transmitted pressures, the modulus of rupture of the material of each pipe, and the influence of the bell of the pipe—should be carefully ascertained and allowed for. Only until after these disturbing influences are taken into account can we hope for a correct formula for strength of pipe, and I believe it will then be found to accord closely to the indications of theory.

The results of the experiments recorded in the second portion of the paper indicate very clearly that the transmitted pressures in recent refilling follow a general law; but the small number of experiments tried would hardly warrant any general conclusions, or an extension of such conclusions to other materials or to the pressures to be expected after the trench refilling has completed its settlement, and it is to be hoped that experiments will be extended along these lines.

There is an old proverb that "every tub must stand on its own bottom," and it seems to me that this must ultimately be the case with earth refilling, and that the entire weight of all earth vertically above must ultimately be borne by the structure beneath.

In relation to the use of concrete around pipes, it not only makes an immovable foundation, but if it is carried around the

sides, above the horizontal diameter of the pipe, in sufficient quantities it prevents the spreading of the haunches, and thus more than doubles the resistance of the pipe to cracking.

Mr. F. A. Barbour (by letter).—Mr. Coffin takes issue with my conclusion—that the recorded pressures in a sheeted box are probably higher than those in a continuous trench. In this he may be right. Theoretically, it seems reasonable that if the sides and ends, by friction, serve as abutments to the arch action of the cohesion of material, then the ends must have their proportionate effect, and a continuous trench must result in a greater net pressure than an inclosed box.

Something may be said, however, in answer to this conclusion. In the first place, the experiments seem to indicate that it is not the actual friction or rubbing of the sides which determines the net pressure. There is very little difference between the trenches sheeted and the trenches unsheeted, in the net pressure transmitted to the pipe.

If Mr. Coffin is right, it would seem that the net pressure in experiment No. 5—that in which the platform occupies the middle third of the trench—would have been greater than in experiment No. 2—that with smooth vertical sheeted sides. Experiment No. 5 was taken transversely, a continuous trench, as compared with experiment No. 2. It is to be remembered that the machine lost no water in these trench experiments, and there was no measurable settlement of diaphragm, when weight was on platform.

In experiment No. 5 the bottom of the trench beyond the limits of the platform settled probably more than the platform; the prism of earth resting on the platform had sides of newly filled earth, also capable of settlement, and yet the net pressure transmitted to the platform was 4 per cent. less than in experiment No. 2, with sheeted sides and ends. Moreover, while the percentage of weight of stones transmitted through 9 feet of earth in experiment No. 2 was 23.5, in experiment No. 5 it was only 19.0.

These were the grounds of my conclusion in regard to the comparative pressure in continuous trenches, and, while it may not be right, I hardly think that Mr. Coffin's objection can be figured out in the way he has done. While theoretically reasonable, I think that, practically, the cohesion which will be transmitted across the shorter distance to the sides of trench will be the determining factor, and while perhaps the pressure in a continuous trench will not be less than in a sheeted box, it will not, at all events, be as much greater as the comparative area of

ends and sides in experiment No. 2 to that of the sides alone would indicate.

In reply to Mr. Fuller, it may be stated that no pipes were jointed together and broken, single lengths alone being experimented upon. It is believed that a bell and socket joint, properly made and thoroughly backfilled and tamped, is stronger than the rest of the pipe, and needs no experimental proof.

The formula, which has been presented rather diffidently as a fair expression of the results of the experiments, may not be that sanctioned by theory. It, at all events, has the merits of simplicity, and, considering all the experimental difficulties enumerated by Mr. Fuller, it probably comes as near to the truth as would the more complicated formula mentioned by him.

Theory indicates that the strength is directly proportionate to some power of the thickness and inversely proportionate to the diameter. With this as a foundation, the formula presented has been made to express the result of the experiments, with due allowance for conditions, of which note was taken at the time of making test.

It is true that in some cases the breaking strength varied 100 per cent. in pipe of the same lot, but in these cases the departure from the average is usually more or less explained by the notes taken at the time, which, owing to the necessary space, were not published.

Mr. Fuller refers to the importance of the tamping of the earth over and around the pipe. This was fully realized and great care taken. The same laborer did all the work, and the same earth and tools were used throughout. It is believed that so long as the personal equation must enter into experiments of this kind better results, in this respect, cannot be obtained. As to the value of the formula, if it helps to more properly proportion the thickness of pipe to the diameter than is done at present, it may serve as a basis for the determination of standard thicknesses, which, it is hoped, for the sake of the manufacturers, will be agreed upon by engineers. It should be accepted until something better, based on experiment rather than theory, proves it to be wrong. Column 3 of Table 4, to which Mr. Eddy has referred, was obtained by adding to the figures of column 2 the net weight of steam roller, which, as indicated by experiments with the stones, would be transmitted to the various depths.

Mr. Manley's experience in rolling streets does not affect the value of this table. A comparison of the net pressure as given in column 3 with the breaking strength of the various pipes shows

that even with 1 foot filling all pipes less than 20 inches should stand, but with a very low factor of safety. House connection pipes, 6 inches in diameter, at depths of 6 feet would have a factor of safety of 4 or more.

It is undoubtedly true that many pipes are cracked that are supposed to be all right. In my own experience an accident in one place led to a more critical examination in other pipe, and cracks barely distinguishable to the eye were found. Had not especial interest been taken in the subject these cracks would probably never have been known.

There are certainly some conditions under which it is not safe to use standard pipe, and it is hoped that this paper may serve as an aid to judgment in deciding upon the danger limit.

A LEVEL OF YE OLDEN TIME.

By Otto von Geldern, Member of the Technical Society of the Pacific Coast.

[Read before the Society, November 5, 1897.*]

Instruments for measuring in horizontal and vertical planes have been in use for many centuries, and, although the mechanical construction of the earlier designs may appear very crude to us now, when compared with our modern instruments of precision, it remains a fact that they were built upon correct mathematical or physical principles, and it is astonishing how much has been accomplished with them. The accuracy of the instrument depends upon the man using it. This was as true in olden times as it is to-day; and, while the precision of the instrument has been brought to a marvelous state of perfection, we would find it pretty difficult to improve upon the man who, say even two thousand years ago, applied his science to the solution of practical geometrical problems of the day.

Hero—about 150 years before our era—was the author of a treatise on surveying, and the possessor of an instrument, perfected by himself, with which he accomplished results, by means of laying off right-angles, and on the principle of similar triangles, that may have been very accurate and must certainly have served the purposes for which they were intended.

One of the principal problems arising then, or in any subsequent century, must have been that of transferring a level from one locality to another. Existing engineering works of all ages proclaim this, and it would be interesting to us now to know with what precision this was accomplished and the nature of the instrument with which it was done. If we dwell for a moment on the extreme care and accuracy with which a modern Y-level is built, in which every attention is paid to the optical requirements, so that they shall harmonize with the fine mechanical features; and if we consider with what painful precision a glass bubble-tube is ground, and the extreme accuracy with which it may be made to operate, it seems almost impossible for us, who are used to such instruments, to conceive how any one could have run a line of levels without them. And yet it was done. It is certain that the earlier methods were incapable of the present refinement of results, but the artisan

* Manuscript received Nov. 23, 1897.—Secretary, Ass'n of Eng. Socs.

then was certainly able to turn the results to practical use; and this is all we can achieve to-day.

The plumb-line, which is normal to a horizontal plane at the point of the plumb; or a body of still water, which indicates a level surface, have always been the natural bases to which levels could be referred.

In the work of the great aqueducts, the Romans employed a rod or stick about 20 feet long, having at its extremities two legs, fastened at right-angles to it. Crosspieces were attached to the rod, upon which were drawn vertical lines that were adjusted to correspond to plummets suspended from the rod. Vitruvius describes such an instrument, called the chorobates. Of the three known methods of leveling, either with the dioptra, the libra aquaria or the chorobates, he considered the latter the most accurate and preferable.

It is interesting to read his suggestions regarding its use. He says: * * * "If the wind obstructs the operation of adjusting the plummets to the lines of the instrument, let a channel be cut on the top of the rod, 5 feet long, 1 inch wide and ½ inch high, and let water be poured into it; if the water touch each extremity of the channel equally, it is known to be level. When the chorobates is thus adjusted level, the declivity may be ascertained. Perhaps some one who may have read the works of Archimedes will say that a true level cannot be obtained by means of water, because that author says that water is not level, but takes the form of a spheroid, whose center is the same as that of the earth. Whether the water have a plane or spheroidal surface, the two ends of the channel on the rod right and left, when the rod is level, will nevertheless sustain an equal height of water. If it be inclined towards one side, that end which is highest will not suffer the water to reach the edge of the channel on the rule. Hence it follows that though water poured in may have a swelling and curve in the middle, yet its extremities to the right and left will be level."*

As it was manifestly impossible to transfer a level with this instrument to any considerable distance, it must have required a frequent repetition of stations in work where a certain degree of accuracy was called for.

The principle of creating a quiet water surface for leveling was applied for many centuries, the original form being improved

*From the "Ten Books of Marcus Vitruvius Pollio," Joseph Gwilt's translation.

until it became more compact and practical, like the old water balance, which many of us remember and have seen in actual use.

There were other principles resorted to, however, one being the suspension or support in its center of gravity of a long and heavy body—like a metal straightedge—which, when thus suspended or supported, would lie in a horizontal plane.

We have records of these contrivances that date back two centuries. Even at that time the level had become a measuring apparatus of considerable refinement, to which a number of accessories had been added; the application of glass lenses was not uncommon, although employed somewhat differently than to-day. A silken thread furnished the horizontal crossbar, which was placed in the focus of the objective lens and viewed through an eye-sight.

In the records of the scientific societies, as far back as the beginning of the eighteenth century, we meet with occasional references to this subject. It seemed to be the evident design then to extend the usefulness of the level so that it might be made operative for long distances without increasing the chances of error, the object being to facilitate the field work without destroying the accuracy.

It is the purpose of these preliminaries to call attention to a memoir, published with the papers of the Royal Academy of Paris for the year 1704; by Monsieur de la Hire, an astronomer, a prominent member and a man of many scientific attainments. That he was most active and fertile is shown by the fact that in the Transactions of the Academy there appear many other papers by the same author on the most diverse subjects, wherein the practical application of science appears to have been the principal object.

The memoir refers to the invention of a new level on the principle of fastening an iron rule at its center of gravity to an upright support canting on its base, the idea being that the rule, once properly adjusted, will always lie in a horizontal plane at the instant when in absolute poise, and indifferent to tipping towards either one side or the other. How he applies this principle to render it practically useful will be best seen in the inventor's description of it, to which attention is now called.

From the author's statements, it becomes evident that this level did not remain an idle invention, but that he must have tested and proved its utility in his work; he says that in a distance of 1¼ miles he was able to obtain a level to within 3 or 4 inches, and he adds that this is all we can hope for.

In this connection it would be interesting to know when all

these older levels were finally superseded by the telescopic level with the attached bubble-tube, for it seems reasonable to assume that from the time of the introduction and use of the bubble there could not have been any further need for the application of any other principle.

A description of the bubble-tube (libella) is mentioned for the first time in a small French pamphlet in 1666. The inventor appears to have been the mechanician Chapotot; but that it was not directly applied in the art of leveling for fifty years afterwards seems evident from the following memoir:

THE DESCRIPTION AND USE OF A LEVEL OF A NEW CONSTRUCTION, BY M. DE LA HIRE, NOVEMBER 12, 1704.

The great aqueducts which the ancients have made might have persuaded us that they were very skillful in the art of leveling, if the instruments which they used, and the whole artifice which they employed, had not been handed down to us in the works of Vitruvius.

The new discoveries that have been made in the Academy of Sciences, and the different levels that have been there invented with telescopes, which serve them for sights, have given us the means of making levels with a great deal more justness, and with much more ease, than all those which have been made till this time; since we may level at once a distance of 1000 toises without any sensible error.

We have in our hands the levels of M. Picard, Mariotte, Huygens, Thevenot and Roemer, whose construction were all different; and I have also given one which draws its justness from the surface of water, a description of which I have printed in M. Picard's treatise of leveling, in 1684, and which was afterwards copied in the memoirs of the Academy, in 1699. But the surveys that I have formerly made, by order of the King, in different places and at different times, for the space of about 100 leagues, have shown me that almost all these levels have great inconveniences in them, and that they cannot be easily transported without our being obliged to rectify them, and sometimes to restore the sights, which require pretty troublesome operations. Not that it is necessary to make use of a just level to make exact surveys, since we may easily arrive at it by taking some precautions, as is observed in M. Picard's leveling, and as I have explained it afterwards in a little treatise of leveling which I have given to the public.

The level which I here describe, and which I made some time ago, is constructed upon a different principle from all other levels

which have hitherto appeared, for they draw all their justness, either from the center of gravity of the body of the whole level, which is suspended upon a body flexible or otherwise, or from a plummet also suspended to a thread, as fine as a hair; or, lastly, from the surface of water, or some other fluid body, whose surface is always level. But this here is not at all suspended by any body whatever; on the contrary, the center of gravity of the body which serves it for a rule, as it does to many others, is placed above the point of support; so that if it was possible that the center of gravity of the body, which is a mathematical point, should remain immovable upon the support, which is the nicest point that it is possible to make, we should then have the true level, which would be the perpendicular line drawn to that which passes through the center of gravity and through the support. But as it is impossible to make the center of gravity stay in a fixed place above the point of support, we take for the true level the position where this point is indifferent to fall either on one side or the other.

It will perhaps be said that this principle is not so just as that where the heavy body is suspended by a flexible body; but if we make the least reflection upon these suspensions, we shall see that there are very great irregularities caused by the nature of these bodies; besides, if the whole machine is exposed to a little wind, it is in a continual shaking and agitation, and it is impossible to determine the level. I say nothing of the remedies that are brought to these shakings, as of plunging the weight suspended to the machine in water or oil to stop the vibrations, since even this remedy has great inconveniences, and yet is not sufficient.

This which I propose is firm, solid and steady, being once well-constructed; and it may be carried about as we please, without being afraid that it may alter; and if it makes any alteration, it will be very easy to rectify it without changing its place, or, as we say, a single station.

The new sights upon glass, as I have proposed them to the Academy, and as they are described in the memoirs of 1700 and in my astronomical tables, give it also a very great advantage above all the rest; for these sights are unalterable by all the changes of the air, and cannot be spoiled by any accident whatever, though they should be at least as fine and slender as the threads of a silkworm, which have hitherto been considered as the most fit to make exact observations with. It is very easy to make them, since it is only a little line or very fine stroke marked with a diamond upon a little bit of glass, which is fixed to the focus of the object-glass of the telescope; for the center of the object-glass is in the room of an

object-sight, and the stroke upon the glass serves for an eye-sight. It is easy to judge that this eye-sight cannot suffer any alteration or change, either by heat or cold, by little insects which fix themselves to the silk, by touching it, or, in fine, by carrying the instrument in any manner whatever; for it will be as solid as the object-sight.

The principal part of this level is an iron rule, which bears at its extremities the sights or diopters, which are an object-glass of a telescope for the object-sight; and for the eye-sight, a little bit of glass with a little stroke, as I have just said. This glass runs in a frame or groove, that it may be stopped at what height we please. This rule is instead of the body of a telescope, which has no eye-glass, and has no other tube than the whole box which is blacked on the inside and well closed.

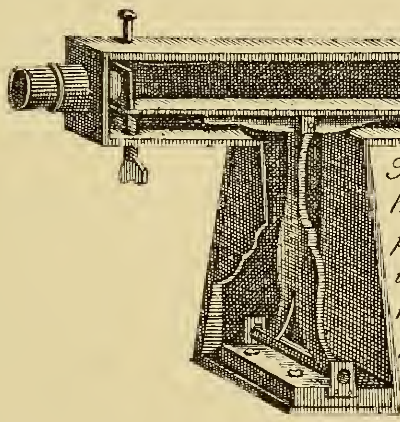


Figure of the Level proposed in it's box with the fore part removed

There is, under this iron rule, another rule placed upon the ground, which serves to make it more firm, and has in the middle another piece of iron or brass about two-thirds of the length of the first, with which it is in a square. This piece increases in width at the bottom, so that the breadth is perpendicular to the length of the rule of the telescope. At the extremity of this piece are soldered on both sides the pivots, upon which the machine moves; and consequently as the whole body of the level is moved when the pivots are pretty near upon a level, the telescope rises and falls in its motion.

There is a little care required in the construction of the pivots. Their cut must be in form of a very acute lozenge, with a sharp point both at top and bottom; for it is by these places that the whole level is sustained upon the support.

The pivots are of tempered steel, and the place where they

bear upon the support is a little hollow, although sharp, that in the motion of the level they may not get from either side. There are two similar cavities opposite to one another, for an use which we shall hereafter explain.

The supports are fastened with screws to a particular piece, which is of wood, and this piece is held in the bottom of the box with screws, in such a manner that it may be drawn out of the box with the whole level which rests upon its supports.

These supports are made of a flat piece of tempered steel, in which are two round apertures, of which the inner one is blunted, to sustain the pivots of the level and to be firm enough not to spoil in the motion of the level.

The box that incloses the level may be made of what figure you please on the outside; but the whole level being of the figure of a T, the box ought to be pretty near of the same figure; and it must hold the instruments in such a manner that it has only liberty to move a little on each side. At the two extremities of the upper part of the box, which is the transverse of the T, there are two round covers, to one of which is fixed the end of the tube where the porte-oculaire enters; for the eyeglass is not fastened to the telescope, and we may by this means bring it nigher or farther from the eye-sight, according to the strength of the observer's sight. The aperture of the other end of the box serves to let the rays of the object pass, which meet the object-glass or object-sight.

Toward the eyeglass at the lower part of the length of the box is a pretty long screw, which moves in a nut fixed to the box. This screw serves to raise the end of the iron rule as occasion requires. The furrows of this screw are very fine to raise the rule, as it were, insensibly by turning the screw.

Opposite to the screw; that is, in the top of the crossway of the box, there is within a very slender spring, which is held to the box by the extremity farthest from the eyeglass; and at the other it bears a peg with a button, which passes to the outside of the box. This peg serves to drive the spring downwards, for in its natural state it is applied against the top of the box on the inside.

There is at the screw a repaire, or mark, to let it into the nut just in this place; and then the rule of the telescope being rested upon the screws, the telescope is over against the apertures of the box.

There is then nothing to be done but to place the sights so that their true line be perpendicular to the plane which passes through the center of gravity of the whole level, and through the line of the supports, and this is called rectifying it; and as all the

parts that compose it are solids, being once well rectified, it will not afterwards change; wherefore it is sufficient to rectify it well in constructing it by some of the ways which are explained in M. Picard's treatise of leveling, by establishing two points of level, and also with the level without being rectified.

TO RECTIFY THE LEVEL.

Supposing then that we have two points of level, A and B, about 100 toises distant from one another; we place the telescope at one end of these points as A, and point it toward the other point B, raising or sinking the body gently. And when the object B appears upon the eye-sight, if the rule of the telescope is placed upon the point of the screw, and it is not in a state of falling forward; that is, towards the object-glass, which we may know by pushing or raising the rule a little by turning the screw; for then the telescope falls lower, and is also placed upon the screw. This shows that the part of the whole level, which is toward the eye-glass, is too heavy; therefore the part of the rule toward the object-glass must be changed by means of a little weight which shall run upon the rule, and may be stopped in whatsoever place we please with a little screw, or only charging it with a little soft wax and lead. We charge this part of the rule so much that the sights, being pointed toward the object B, are indifferent to rest upon the point of the screw, or to fall forward, and then it will be rectified.

But if at first the sights being pointed toward the object B, the rule cannot keep upon the screw; we shall know by that that the part of the level toward the eyeglass is too light, and then it must be charged, as was done in the other case, till the level is in an indifferent state of falling or resting upon the point of the screw; and then the level will be rectified.

We might also, instead of charging the rule on either side, raise or sink the eye-sight in its frame, till the level was just, which we might do if the level is not far from being just.

We shall observe that in these operations every time that the telescope falls forward it is replaced upon the point of the screw, by pushing the spring at the top of the box, which drives the frame of the eye-sight downwards, and by that means replace the rule upon the point of the screw.

As this level may be put in a reverse situation, which is when the telescope is below the pivots, we must explain what ought to be observed in the constructing of it to serve in this state.

It is certain that if the pivots were a mathematical line, when the level is reversed it would point to the same place where it

pointed in its right situation, provided that this place was perfectly level with the place where the level is situated; and to rectify it we need only aim the telescope at the same point in the two situations of the level, by increasing or diminishing by degrees the weight of one of the ends of the rule. But as the pivots must have a considerable thickness to make them solid, it may happen that the plane, which passes through the center of gravity of the whole level, and through the line where the pivots rest, will not be the same in the two situations of the level; it must be rectified in the reversed position, the same as in the right. But as we must not change the sights which are rectified for the right position, we must correct the place of the pivots where they bear upon the support in the reverse position.

The level being therefore reversed, if the sights do not give the same point as in the right situation rectified, the pivots must be filed a little to drive the point toward the object-glass, if the sights fall too low in the reverse situation, or toward the eyeglass if they rise too high.

The pivots may also be made in another manner, so that the plane which shall pass through the center of gravity of the instrument, and through the place where the pivots rest, shall be the same, both in the right and reversed situation of the level; and thus we may rectify this level from a single station, without having a line of level.

In this second manner the pivots must be cylindrical, and very well turned and polished in the places where they bear upon and touch their supports, which ought to be a little hollow, like a pulley. Besides, the bottom and top of the hole of the support which sustains the pivots must be almost in a right line, that the pivots may not touch sensibly but in one point.

It is evident that in this construction of the pivots the center of gravity of the level, and the line which shall pass through the places where the pivots rest in the two situations of the level, will be always in the same plane, which shall also pass through the axis of the cylinder of the pivots.

This suspension of the level is not so nice as the first, because the place of the pivot, where it touches upon the support, is of circular figure; and in the first it is of a pointed figure, a little blunted.

THE USE OF THE LEVEL.

To make use of this level we must first put the screw to its mark, that the sights may be over against the apertures of the box. Afterwards, by means of the springs, we drive the rule of the tele-

scope against the end of the screw, in such a manner that it does not fall from the other side, which is easy to do by inclining the box; and in this state the rule of the telescope, being placed upon the screw, without the spring holding it, we bend the box by degrees toward the end, where the object-glass is, till the telescope falls on that side. Then we hold the box as firm as possible in this state, either upon a foot or against some other solid body; the telescope must be then pointed toward the object that we would level, and we ought to observe exactly the part of the object that appears upon the stroke which serves for an eye-sight. But as I suppose the telescope to be placed upon the screw, we must push the screw gently till the telescope falls on the other side, and observe well the part of the object which appears upon the stroke when the telescope falls; and to be assured of it, we must drive back the telescope upon the screw by means of the spring, and observe if it falls again; and if the same object appears upon the stroke of the glass which appeared there before, we should then undo a very little part of the screw and, driving back the telescope upon the screw, observe what difference there shall be between the object which shall appear upon the stroke in this state of the telescope and that which appeared there before. It must also be considered if the telescope rests then upon the screw, or if it falls again from the other side; for to have the point of the level just, the telescope, being placed upon the end of the screw, must be in a state of falling on the other side without falling, and we cannot raise it the least with the screw without its falling; it is then that the object, which appears in the telescope upon the stroke of the sight, is in a level with the stroke of this sight.

What I say of the level must always be understood of the apparent level, with the relation to the place where the instrument is, which serves to level, as it is explained in the treatise of leveling; for to have the true level corresponding to that where the instrument is placed, we must make the correction to the apparent point of level, with relation to the distance between the place where the instrument is and the point leveled; but we do not here treat of this practice of leveling.

One of the advantages of this level is that it may be reversed and serve again to level in this situation without any preparation or change, and though it has then some vibrations, they last but a little while, for they come only from the body of the instrument, and not from the motion of the box, which must be held firm, but without any subjection, since it loses nothing of the justness of the level; we may also easily stop the shaking of the level by support-

ing gently the spring against the frame of the sight, and by letting it afterwards replace in its natural state.

The size of this level is not at all determined, for the greater the telescopes are the more distinct the distant objects will appear; but it will be much more inconvenient to be carried about.

I have proved that one of these levels, whose height and length was but 10 inches, determined the level to near 3 or 4 inches at a distance of 1000 toises (6400′), which is all we can hope from a level, since an object of this bigness, at this distance, is entirely covered by a single thread of silk.

We may make use of different supports, but one of the most convenient ways for practice will be to fix the box of the level very firm, with a screw, against the cross of a painter's easel, which is solid; we might also hold it only in the hand, and bear it against some very stable body, whilst the operations are performed.

It must be observed that when we would transport this level, the pivots should not bear at all upon their support, which will be very easy if these pivots jut a little out of the box, and if there are in this place upon the box two sorts of hooks, which are engaged in the ends of the pivots and hold all the level raised out of the supports. We might also fix the telescope against the end of the screw by means of the spring, which shall be rested upon the sight; but if we would open the lid of the box we might engage the whole level between some brackets, which will hinder it from balancing on one side or other in carrying it a long journey.

DISCUSSION.

Mr. Adolph Lietz (Member Technical Society).—Mr. von Geldern's paper is of great interest; our engineers, accustomed to handle instruments of the latest improved style, ought to feel a certain amount of comfort in comparing a level of the olden times with a modern instrument.

The constructor of the level described places importance upon the adjustment, which can be effected without removing the instrument from its station, a feature preferred by our engineers to-day, for they generally demand the Y-level, which can be adjusted from one station. It appears that the reason for this preference is not well-grounded, as it is generally coupled with the idea that such instruments are capable of doing more accurate work than the Dumpy level.

Many engineers condemn the use of Dumpy levels without sufficient reasons. It is true that instrument makers in this country have not generally advocated the introduction of this old, use-

ERRATUM IN DECEMBER NUMBER.

Page 253, 7th line,

For—

"level, which has lately come into general use, it makes the ideal"

Read—

"level is simplicity in construction, insuring steadiness, permanency,"

ful and, in Europe, more universally employed tool; but it must be remembered that the maker often meets with difficulties by introducing a new instrument or, as in this case, an old one, of which the professional engineer is not aware. If a Dumpy level is properly constructed, and if its mechanical and optical requirements are up to the standard, its principal advantage over the Y-level, which has lately come into general use, it makes the ideal of adjustments and reduction in price.

If the Y-leveling instrument is supplied with the reversion level, which has lately come into general use, it makes the ideal leveling instrument of to-day for the American engineer; for the reversion level admits of running true levels, regardless of the adjustment of the instrument, by a method of vertical double centering.

The idea prevails among engineers generally that a perfect adjustment of a Y-level can be effected from one station. This is not quite true. Even if the telescope collars are not of exact equal diameters and perfect cylinders, but if the Y's are both filed out to the same angle (this is generally the case, or at least very nearly so, as most makers file them out by means of gauges) it may be so adjusted that the bubble on all reversals in the Y's and revolutions on center will always give the same reading at both ends; that is, indicate a true horizontal position. To ascertain whether the instrument is true, however, can only be done by the three-stake adjustment,—except when a reversion level is adopted, as referred to before.

The reversion level can, with equal advantage, be applied to the transit, and it has already found a wide application in this capacity during the last years. While the reversion level is not new, its early application was prevented chiefly by its high price, which is reduced now by improved methods of production. Some years ago I was requested by Mr. C. S. Batterman, mining engineer, to construct a level for a transit telescope, which, according to his design, should revolve on its axis, and thus fulfill the duty of a reversion level; this was made and, I believe, has given satisfaction. The objection, however, will remain that adjustments which have to be provided are liable to change, and may need attention now and then; its cost, also, is higher than the reversion level, as applied to-day. The reversion level may also be applied with equal advantages in other directions.

I first adopted it in the capacity of a striding level for a high grade theodolite, built some months ago, and I believe that in time it will find a wider application for such purposes.

It is interesting to learn that the spirit level, now so universally applied, was not generally in use for leveling two centuries ago; and we have some reasons to consider this authentic from the fact that the author of the original paper just read does not refer to it; and we may take it for granted that the instrument and methods of the principal geometer of his time, Monsieur Picard, were known to him; and had Picard employed the bubble tube for leveling, or had he referred to it in his treatises, it is reasonable to suppose that de la Hire would have mentioned it. This is all the more astonishing since the spirit level was not entirely unknown, for it had been described as early as 1666.

I would like to branch off at this point, and, if you will permit me, I will make a few statements about modern surveying instruments from the standpoint of the instrument maker.

A prominent feature of a modern level or transit is the telescope. It is true to state that every advance in optical science has brought an improvement to it.

The requirements are power, definition and light. How to combine these best, and not increase the advantages in one direction without a loss in another, is the study of the instrument maker. And a very difficult one it is—and a thankless one, too,— for nothing is understood and appreciated so little as this particular feature, even among our best engineers, who often find fault where no fault can be proven. I am glad to have this opportunity to discuss this subject before the Society, and, while it may digress somewhat from the original subject, it will be of interest to you to learn what is demanded of a telescope to-day.

The introduction of the Jena glass was an achievement in the manufacture of telescopes for surveying purposes; and with the best material now on hand, it behooved the optician to make his lenses and lens-systems, and the instrument maker to study the conditions under which they had to be applied to furnish the best results in the field practice of the engineer.

I have had experience in this direction, and the statements that I shall make are based upon practical tests that I have had frequent occasion to carry on.

Assuming that the mechanical work of a telescope is of high order, and that the best lenses obtainable have been properly fitted, its capabilities depend upon the amount of light admitted and the magnifying power. An increase of power without corresponding increase of light is of no particular gain; and by using too low a power we do not get all the optical effect of a first-class objective. There must be a certain proportion between aperture and focal

length from which the most practical result might be expected. This matter has had the consideration of some of the most eminent opticians.

It is generally assumed, and we have practical reasons for it, that the best effect is obtained if an objective with a $1\frac{1}{8}$ inch aperture, having a certain focal length, be supplied with an eyepiece resulting in a telescopic combination of a magnifying power of 20. For instance, with an objective focus of 10 inches, the equivalent of the eyepiece should be $\frac{1}{2}$ inch. The $1\frac{1}{8}$ inch aperture will then admit the necessary amount of light.

The area of an objective with a diameter of $1\frac{1}{8}$ inches is nearly 1 square inch; by increasing the diameter to $1\frac{5}{8}$ inches the area is doubled, and twice the amount of light is admitted. It might now be inferred that the magnifying power could be proportionately increased, and that we should be justified in making it 40 instead of 20. Practice has taught us, however, that this is not applicable —that this light relation cannot be extended—and that a better result is achieved if we stop at a certain power and increase the amount of light instead. The reason for this is found in the disturbing influence of the atmosphere, which grows with the magnifying abilities of the telescope. Every floating particle in the air, and every motion and reflection of the light-wave is brought out so much more distinctly that a clear and well-defined image will become an impossibility; and the observer may be effectually brought face to face with the paradox that he will be able to see more and better with the naked eye than with a high-power telescope.

This accounts for the fact that telescopes are often condemned, that in reality possess excellent lenses, but too high a power; while others again are commented upon for their clearness that may possess very ordinary glasses. There is, therefore, a certain limit to the magnifying power of a surveying instrument that it is wise not to overstep, if we would retain a clear image. A practical ratio between focus and aperture is about 10 to 1.

Of two telescopes of even workmanship and the same focal length, the one with the greater aperture will show a clearer and better image. And in this connection it is well to notice the unexplainable fact of the existence of diaphragms within the tube to shut out the light. Why should this be resorted to when the necessity of light is so apparent? With a well-ground and corrected lens there is no need of placing any obstruction in the way of all the light it will admit. In faulty lenses there may be sufficient reason for such a course, but there is no excuse for using anything of that character in a modern telescope. Instead of

blinding a first-class lens, would it not be more reasonable to adopt a smaller lens, a shorter tube, and thus build a lighter instrument?

A telescope intended for tachymetric or stadia measurements must possess all the qualities mentioned to their very best advantage, particularly distinctness, in order that a graduated rod may be read long distances with the greatest possible accuracy. Correct determinations of distances are impossible with a poor telescope. The lenses should be of the Jena glass, accurately centered, and the eyepiece of the inverting form, which admits of the use of an objective of greater focal distance with the same length of telescope than the combination for erect vision.

In using the erect ocular, too much is sacrificed for what is only an apparent advantage, and I will go so far as to say that all good telescopes intended for tachymetric determinations should have the inverting eyepiece. That this form is not readily obtained in a manufactured surveying instrument in this country is not the fault of the maker, but is simply due to the fact that an unwarranted preference is given to an erect vision.

Assuming the focal length of an objective, f, as a constant (which it is, except for very short and inadmissible sights) the ratio between it and the distance between the threads s is the fundamental basis underlying this method of measuring, for f/s usually termed K, represents a constant by which any intercepted rod space must be multiplied to obtain the distance from the instrument to the road. We know that this refers to observations parallel to the horizon, and that it is customary to place the hairs so as to make the ratio 1 in 100.

In perfecting the optical features of an instrument, it was sought to obviate the necessity of correcting for the distance of the anallactic point. Since stadia measurements originate from the outer focus of the objective lens, and not from the center of the instrument, it becomes somewhat troublesome to apply a correction therefor on inclined sights, for, since the corrections remain constant for any distance and vary with the angle of inclination only, it is not practical to incorporate them directly into the tabular values employed in reducing stadia observations. Such tables are usually augmented by placing the corrections, due to what is generally termed the constant c at the bottom thereof. To overcome this difficulty, and to make every reading date directly from the center of the instrument, the Italian Porro invented a method in 1823, which is now beginning to be better known. This method has been frequently discussed. The *Journal of the Franklin Institute* contains an article in a number as far back as

1868. The *Engineering News* of November 8, 1890, has a short discussion by one of our best writers on these subjects, Professor J. B. Johnson, of the Washington University, St. Louis.

A convex lens of required focal length is inserted between the objective and the eyepiece, which transfers the anallactic point to the occupied center. Theoretically this is necessary, for the observed vertical angles have their common vertex in the center of the arc, or horizontal axis of the telescope; while the vertex of the diastimometric angle lies outside of the objective, a distance of 14 inches from the center of the instrument in the ordinary large transit. This would cause slight errors in vertical angle and distance, which disappear in the Porro telescope.

There are very substantial reasons, however, why this anallactic lens has not found a more general application in modern surveying instruments, for it is not a new thing with which we are dealing, but a principle that was known and used over half a century ago; and these reasons will now be briefly considered.

By inserting an additional lens the equivalent focal length of the objective is considerably decreased, and the power and capacity are thereby correspondingly lessened. To exemplify this, reference is made to an actual test of which the results were accessible to me. In this case the focal length of the objective equaled $13\frac{1}{2}$ inches, that of the inserted lens 5 inches and the distance between them $9\frac{3}{8}$ inches. The equivalent focal length of the combination was therefore $7\frac{3}{8}$ inches. The image of the system lay $2\frac{1}{4}$ inches behind the anallactic lens, and its distance from the objective therefore $11\frac{5}{8}$ inches. Here we notice that the available focal length has been shortened by the lens combination $4\frac{1}{4}$ inches, which is a direct loss of nearly 37 per cent. An ordinary telescope with a focus of $11\frac{5}{8}$ inches, possessing an eyepiece with one of $\frac{1}{2}$ inch, would have a power of 23; while the Porro telescope under similar conditions shows only 15, indicating the same perecentage of loss in power. There is, however, a slight gain in brightness with the same aperture of objectives, for the reason that the admitted light is concentrated in a smaller space. In order to make up for the loss in power, due to the anallactic lens, a more powerful eyepiece must be made use of. One with an equivalent focal length of 5-16 inch would about compensate the 37 per cent. of loss, but the brightness of the image would not then be quite up to that of the ordinary telescope, since the middle lens will cause a slight loss of light by reason of reflection and absorption. This, however, might again be rectified by giving the objective a somewhat larger aperture.

While it is readily seen that a Porro telescope might be constructed fully up to the capacity of our ordinary transit telescope, it is also apparent that much greater care and refinement would have to be resorted to to reach it, for it is very important that the entire mechanical work should be perfectly in harmony with the greater optical requirements. The tubes must be absolutely straight, the axes of the lenses must be identical and their principal planes normal thereto. Greater care must be exercised in the construction of the objective, it being necessary to correct therein for the aberration due to sphericity and achromatism of the anallactic—which is usually a simple convex lens—if we would retain a clear and distinct image.

It is a problem for the instrument maker to construct the Porro telescope so that there shall be no complicated parts, and no excess of cost to speak against it. The additional lens, whose focal distance depends upon the length of the telescope and the location of the center of the instrument, is placed in front of and not too far from the cross-hair diaphragm. Its distance from the objective must necessarily remain constant, and any motion of the latter in the tube must be made with the middle lens also. The lenses must move together.

It might be a more advantageous construction to adopt the movable eyepiece, and to focus by shifting the cross-hair diaphragm in connection therewith.

This lens combination has one peculiar advantage that must not be left unmentioned, which is that it requires but a very small telescopic slide movement to focus from long to short distances and *vice versa*. A range of half an inch may be sufficient to cover all the required lengths of sight.

In building the tube, provisions must also be made for readily removing the inner lens in order to clean it, which would probably be frequently required. The arrangements for this purpose must be so contrived that the lens may be replaced in its proper position and accurately adjusted to the required optical conditions.

Every feature goes to show that the mechanical work of such a telescope must be of the highest order, if it shall meet the demands made upon it. With the cheaper grade of surveying instruments a Porro telescope is an impossibility. Whether the extra cost necessarily connected therewith will be justified by the gain of the slight advantage in obliterating the constant c, is a matter that shall be left to your judgment. I am of the opinion that the smaller the number of lenses used in the construction of surveying telescopes the better will be the results, and the less the

structural refinement required to lead to them. Granted that we have a Porro telescope fully up to the power and capacity of that of the simpler construction, there are the constant disadvantages of using a powerful microscope, which must be more or less fatiguing to the eyes of the observer; and the accumulation of dust on the inner lens, a difficulty that may lead to considerable trouble and annoyance. These reasons have been more than sufficient to prevent the anallactic telescope from being generally introduced and practically used. It is granted, however, that, as a precise instrument, it is perfectly within the reach of the optical and mechanical arts to build one that shall fully accomplish the translation of the anallactic point to the center of the instrument.

From the beginning of the eighteenth to the end of the nineteenth century, what improvements have been made to furnish the engineer with a practical, useful and reliable tool for measuring. Compare de la Hire's level with one of your modern Y-levels. Compare his telescopic accessories with the refinements of to-day, which seek even to destroy the small anallactic difference in measuring distances telescopically, which could be so easily and readily corrected—if at all required—by a computed table or slide rule.

THE SHEARING STRENGTH OF WIRE NAILS.

A Thesis: By Frank Bates Walker, for the Degree of Civil Engineer, and Chas. H. Cross, for the Degree of Mechanical Engineer, University of Minnesota, May, 1897.

[Read before the Civil Engineers' Society of St. Paul, April 5, 1897.*]

At the suggestion of Mr. A. W. Muenster, bridge engineer of St. Paul, the writers chose for their graduating thesis the subject of the shearing strength of wire nails. There appears to be but little record of research on this subject, yet the nailed joint or splice is a matter of everyday practice, and some definite knowledge of the action of nails in this connection would seem to be desirable.

Trautwine gives the only data on the subject found in any handbook. He says (on page 425): "Boards of oak or pine nailed together by from 4 to 16 10-penny common cut nails and then pulled apart in a direction lengthwise of the boards and across the nails, tending to break the latter in two by a shearing action, required about 300 to 400 pounds per nail to separate them, as a result of many trials." But this is not sufficiently specific to be of much practical value.

Experiments were made by Mr. F. W. Clay, C. E., Cornell, '93, on the shearing strength of nails, results of which are given in his thesis, entitled "Experiments to Determine the Holding Power of Nails and Drift Bolts." They were published, also, in *Engineering News,* January 11, 1894. Mr. Clay's experiments were made mainly to determine the comparative holding power of cut and of wire nails, pulling them out in the direction of the length of the nails.

His tests for the shearing strength seem to have been merely a side issue. We give, in Tables I and II, his experiments on shear. In regard to Table I, Mr. Clay says that he did not drive the heads of the nails up to a good bearing, but let them project a little, so as to get no effect of the head in the test. In Table II the nails were all driven the same depth into yellow pine and held on cleats of oak. The maximum pressure began soon after the cleats began to move. He does not state definitely, but he probably used cut nails only in Table II.

*Manuscript received November 29, 1897.—Secretary, Ass'n of Eng. Socs.

TABLE I (CLAY).

Holding power of wire nails and of cut nails subjected to a shearing strain.

Kind of wood, size, etc.	Size of Nail.	Stress per Nail.
Two slabs of 2-inch Georgia pine	12d. cut	950
" " " " " "	12d. wire	745
" " " " white "	12d. cut	905
" " " " " "	20d. wire	540
1-inch Georgia pine to 5-inch hemlock	20d. cut	870
" " " " " "	20d. wire	647
" " " " 3-inch oak	6d. cut	527
" " " " " "	10d. wire	526

TABLE II (CLAY).

Resistance to shearing stress by nails of different sizes.

Size of Nail.	No. of Nails.	Area in Wood.	Stress per Nail.	Stress per Unit of Area.
50d.	3	0.833	846	1015.6
20d.	3	0.580	533	918.9
18d.	3	0.566	490	865.7
15d.	4	0.471	375	796.2
10d.	5	0.427	452	1058.5
6d.	6	0.330	283	857.5

Prof. R. C. Carpenter made extensive experiments on the comparative holding power of cut and of wire nails, and the results were published in the "Proceedings of the American Society of Mechanical Engineers," vol. 16, page 1002, under the title of "Force Required and the Work Performed in Driving and Pulling Cut and Wire Nails." No results were found of tests on the present woods of construction and the larger-sized nails and spikes.

Having given a *résumé* of about all that could be found on the subject of shear, the writers will state briefly how they conducted their experiments and give the tabulated results.

About 300 experiments in all were made on the various sizes of wire nails, including a few on 7 and 8-inch square boat spikes. The primary object of the entire series of experiments was to determine the maximum allowable stresses which could be used in actual practice for the various sizes of nails.

The experiments were made as simple as possible. Two planed blocks were nailed together by one or more nails or spikes and then pulled in the same manner as above described by Trautwine. To facilitate the work, two clamps of $\frac{1}{2}$-inch boiler plate, bent into U shape, were made to use with a small Olsen testing machine in the University laboratory. These clamps are shown

in position on the machine in Fig. 1. They are about 5 inches deep and about 6 inches square on the base. Two screws, with hand wheels, grip the specimens firmly and allow the pieces to be easily removed when tested. When the size of the nail required blocks larger than could be easily held, the clamps were not used; the ends of the blocks being sawed off square, they were placed between the pulling head and the weighing table of the testing machine, the load being applied the same as before. Care was taken that the pressure was applied directly through the nail and joint in both planes, in order to prevent any twisting motion of the pieces. In several cases where the first method was used the clamps held 2500 pounds before failing to hold the pieces. The entire holding action of the clamps was due to the

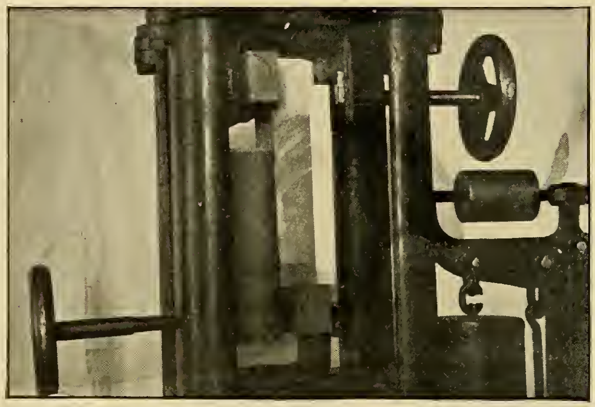


Fig. 1. Testing Machine.

friction and slight crushing of the test pieces between the screws and the sides of the clamps.

The length of the blocks and planks varied from 8 to 15 inches, and the width from 2 inches (when the 6-penny nail was used) to 6 inches (when the 50 and 60-penny nails and larger spikes were used). In only one or two cases did the planks split, and then the splitting was not due to lack of width. The thicknesses of the pieces experimented with were 1, 2, 3 and 4 inches, commercial sizes.

A lead-pencil line was drawn across the joint so as to indicate any movement; and later, when loads were read at the definite extensions, fine lines were drawn on the joint $\frac{1}{8}$ inch apart, and the extensions were read somewhat as with a vernier. By this means spaces could be read up to 1-64 inch, if desired, but nothing was noted nearer than 1-32 inch.

All surfaces in contact were planed, in order to eliminate, as far as possible, the friction of the joint. There was no space between the surfaces, the joint being closed up tightly to prevent unnecessary bending movement in the nails. The sizes of the nails used are given in Table III, together with the sizes as given in Carnegie and in Kent.

TABLE III.

Sizes of wire nails in the present experiments.

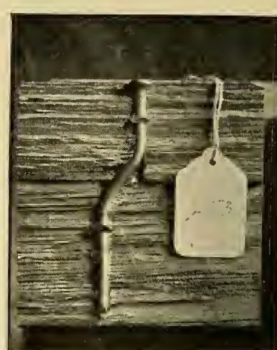
No.	Length.	Actual Dia.	No. per lb.	Dia. Carnegie.	Dia. Kent.
6d.	2″	.110″	196	.0808	.104
8d.	2.5″	.128″	109	.0935	.116
10d.	3″	.152″	64	.1082	.160
16d.	3.5″	.148″	60	.1285	.144
20d. ....'....	4″	.197″	29	.1620	.192
30d.	4.5″	.205″	25	.1819	.212
40d.	5″	.226″	17	.2043	.232
50d.	5.5″	.243″	13	.2294	...
60d.	6″	.261″	10	.2576	.276
80d.	7″	.303″	7	....	...
100d.	8″	.366″	5	....	...
	7″	.375″	Square, chisel-pointed boat spikes.		
	8″	.375″	"	"	" "

The wood was common Norway and white pine, sawed in 1896, and purchased by us in Minneapolis in March, 1897, it having lain in the lumber yard all winter. At the beginning of the experiments it was medium dry, but it became drier during the progress of the work, as it was in a steam-heated building. The oak was well seasoned and brittle.

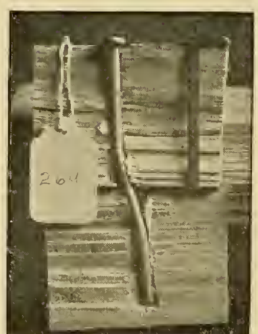
In each table are given the thickness and the kind of each piece of plank and each size of nail used. In every case the thickness of the block (or lower piece) was great enough to cover the point of the nail. No more than this was necessary, the width being sufficient to prevent splitting.

The figures in the column headed "Elastic Limit" (zero extension) indicate the loads at which the pieces begin to move past each other, or the point where the nail begins to bend and the wood to crush. It is not theoretically the elastic limit, for the wood and nail still retain some spring. If, after the pieces have moved 1-16 inch, the load which caused that extension be removed entirely, the joint retains enough elasticity to return practically to its original zero; but, if loaded beyond this 1-16-inch point, the joint returns only a part of the way when the load is removed. The column marked "Return Unloaded" gives this

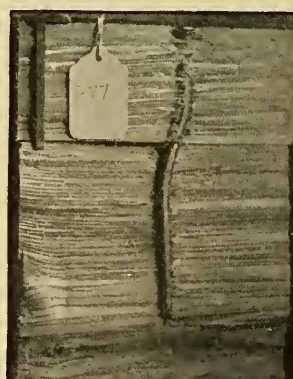
30D. Nail in Oak.



40D. Nail in Oak.

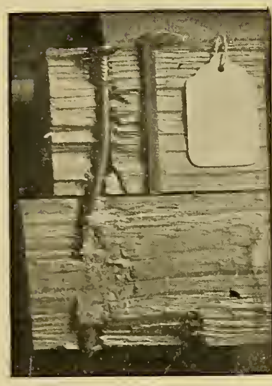


60D. Nail Shortened to 5¾ in. in N. P.

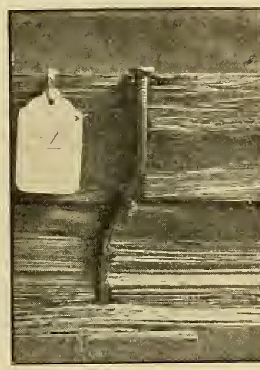


7 in. Nail in N. P.

Fig. 2.

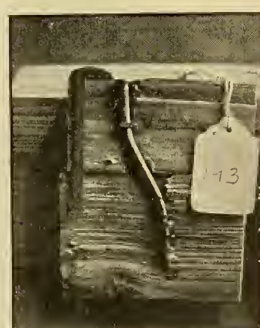


60D. NAIL IN N. P.



50D. NAIL IN N. P.

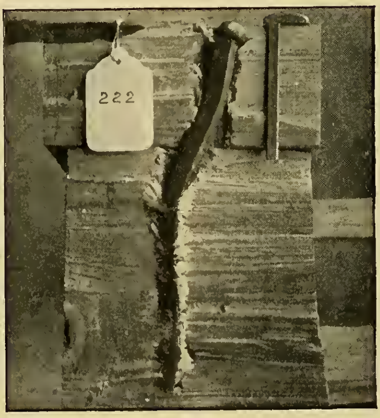
20D. NAIL IN N. P.



30D. NAIL IN N. P.

FIG. 3.

7 in. Square Spike in W. P.



8 in. Square Spike in W. P.

Fig. 3*a*.

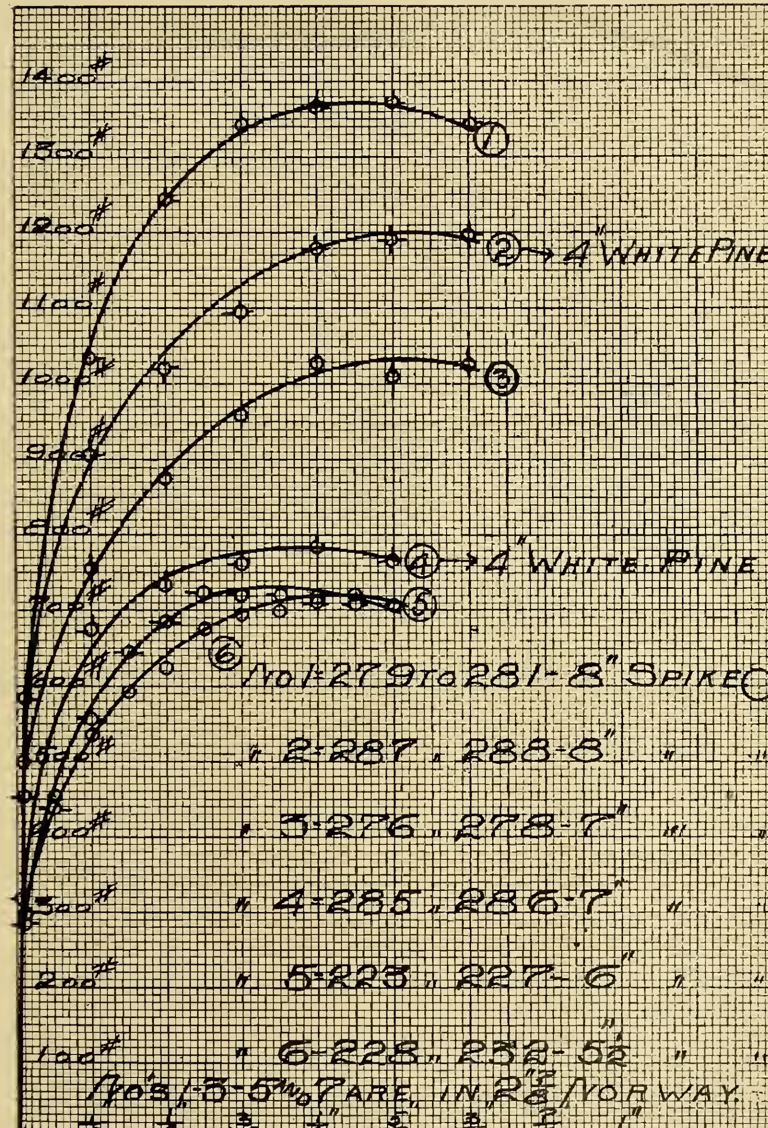


FIG. 4. EFFECT OF SIZE OF NAIL.

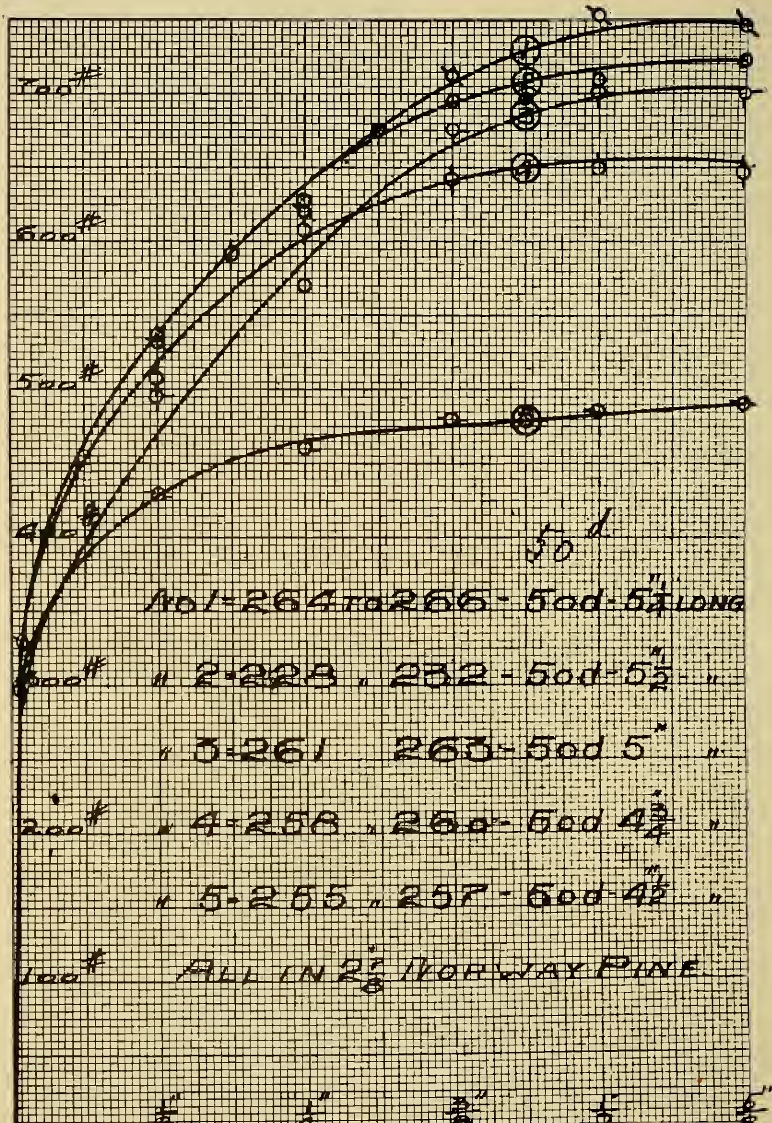


FIG. 5. EFFECT OF REDUCING LENGTH OF NAIL.

distance after the maximum load has been applied and then removed. It shows, in some measure, the elasticity of the joint. If now a certain load or pressure causes an extension of $\frac{1}{8}$ inch, we find that when this load is taken off the pieces will return about 1-16 inch only by their own elasticity, it being necessary to apply a slight pressure in the other direction to return them to their original zero. The pressure being again applied, a small load is sufficient to bring them to the 1-16-inch point, and when that point is passed the load gradually rises to the amount supported at the $\frac{1}{8}$-inch point previous to the removal of the load. This action seems to be practically true for all sizes of nails and spikes. The action of the square spikes is by no means as symmetrical as that of the round ones. It will be noticed that the "Return Unloaded" and the "Extension at Maximum Load" are very nearly constant for all the nails, and that the elastic limit is practically one-half the maximum load.

All loads are given in pounds, and the extensions in inches or fractions of an inch. It was found that, after the load had been on a short time, the joint would not sustain as great a pressure as was required to move the pieces. This was probably due to a readjustment of the internal conditions of the joint itself. The various loads recorded in all the tables following Table IV and all tests on nails larger than 50-penny in Table IV were read about 30 seconds after the extensions had been made. This gave the joint time to make the most of its readjustment. The readings in the latter tables are from 10 to 15 per cent. lower than they would have been had they been taken immediately. This "settling" of the load continues during considerable time, but the maximum change takes place in the first half-minute. One time the test gave the following results: Three 50-penny nails, in $2\frac{5}{8}$-inch Norway pine plank, were subjected to a pressure of 600 pounds. In three hours the load had fallen back to 520 pounds (machine was not moved in the meantime), and in 48 hours the load sustained was 450 pounds, showing a fall of 25 per cent. Then the pressure was run up to 850 pounds (the elastic limit of the joint), and in five days the load sustained was 780 pounds, showing a fall of 8 per cent.

The square spike has the greater maximum strength, but a lower elastic limit, than the round wire spike.

A few experiments were made on 2-inch oak for comparison with the other woods.

The bends of the nails in the oak tests are very short and quite symmetrical. They vary in length in the 20-penny nails

TABLE IV. SINGLE NAIL TESTS.

No. of Tests.	Size of Nail.	Timber. Through.	Timber. Into.	Elastic Limit. Max.	Elastic Limit. Min.	Elastic Limit. Mean.	Maximum Load. Max.	Maximum Load. Min.	Maximum Load. Mean.	Extension under Max. Load, inches.	Return Unloaded, inches.	Load Observed.
*10	6d.	1 in. W. P.	N. P.	100	50	71	180	120	149	1/8 to 1/2	1/32 to 1/16	Immediately.
†10	8d.	"	"	130	85	98	250	170	189	"	"	"
‡10	10d.	"	"	140	90	122	270	215	246	"	"	"
10	16d.	"	"	150	100	126	325	225	279	"	"	"
10	20d.	1 7/8 in. W. P.	"	250	185	220	480	400	431	3/8 to 1/2	1/8	"
10	"	2 1/8 in. N. P.	"	230	180	207	500	400	466	"	1/16	"
10	30d.	1 7/8 in. W. P.	"	300	240	262	500	420	476	3/8 to 1	1/8	"
10	"	2 1/8 in. N. P.	"	250	210	233	580	460	516	1/4 to 3/8	1/16 to 1/8	
10	40d.	1 7/8 in. W. P.	"	360	250	308	760	500	638	3/8 to 1/2	1/8	
10	"	2 1/8 in. N. P.	"	320	280	305	730	590	656	3/8 to 1/2	1/16 to 1/8	
10	50d.	2 13/16 in. W. P.	W. P.	360	300	347	920	725	800	1/4 to 1/2	1/32 to 1/8	30 seconds after extension.
‖10	"	2 7/8 in. N. P.	N. P.	530	320	413	1130	730	821	3/8 to 1	1/16 to 1/8	"
§5	"	"	"	310	280	298	740	640	710			"
10	60d.	2 13/16 in. W. P.	W. P.	350	310	334	860	760	815	1/4 to 1/2	1/16	"
**9	"	2 7/8 in. N. P.	N. P.	510	350	444	950	700	844	3/8 to 1/2	1/16	"
††5	"	"	"	360	200	282	800	650	730			"
2	"	"	"	430	400	415	940	870	905			"
2	7 in.○ wire nail	2 3/4 in. W. P.	W. P.	550	450	500	1020	980	1000	1/2 to 5/8		"
2	" "	4 in. W. P.	"	330	300	315	800	780	790	1/2		"
3	" "	2 7/8 in. N. P.	"	550	450	500	1050	1000	1030	1/2 to 3/4		"
3	7 in.□ spike.	2 3/4 in. W. P.	"	520	400	440	1930	1760	1845	1 1/4		"
3	8 in.○ wire nail.	"	"	600	550	583	1460	1260	1373	1/2 to 3/4		"
2	" "	4 in. W. P.	"	460	450	455	1230	1190	1210	"		"
2	" "	4 in. N. P.	N. P.	550	500	525	1370	1260	1315	1/2 to 5/8		"
5	8 in.□ boat spike.	2 3/4 in. W. P.	W. P.	600	400	470	2000	1830	1955	7/8 to 1 1/4		"

* For five of the tests, the elastic limit=70 pounds.
† Two of the tests were in sap wood; elastic limit=90 pounds.
‡ One test in sap wood; elastic limit=105 pounds.
‖ In seven of the tests, the timber was highly seasoned, which accounts for the high resistance.
§ These tests were made to determine relation between load and extension (see Fig. 5), and elastic limit has possibly been taken at a somewhat lower point than the other tests. The maximum load shows, however, that the tests run low.
** Lumber highly seasoned.
†† Tests to determine relation between load and extension. Nail 1 inch from edge and 1 1/2 inch from end of plank. Slight split in plank from driving of nail did not increase during the test.

from 1$\frac{3}{8}$ to 1$\frac{1}{2}$ inches for the same extension of $\frac{7}{8}$ inch. It is very interesting to note the relation between the hardness and thickness of the wood, the length of the nail and the resulting bend. The photographs also show the fibers of the wood as affected by the penetration of the wire nails, the round spikes and the chisel-pointed square spikes. To find what length of nail was necessary to develop the full strength, it was suggested that experiments be made on 50 and 60-penny nails diminished in length by regular amounts. This was done, and the results with 50-penny nails are given in Table V, Fig. 5. It is seen that the elastic limit is very nearly constant, but that the maximum loads fall off for the shorter nails.

Table V.

(See Fig. 5.)

Effect of length of nail.

No. of Tests.	Nails.	Through.	Into.	Length of Nail Inches.	Average Load at Extension of—						
					0	⅛	¼	⅜	½	⅝	¾
3	1-50d. wire.	2¾″ N. P.	N. P.	4½	320	430	460	470	486	490	480
3	1-50d. "	2¾″ "	"	4¾	307	507	607	643	650	646	
3	1-50d. "	2¾″ "	"	5	300	496	570	670	700	700	
3	1-50d. "	2¾″ "	"	5¼	333	533	620	713	753	743	

As might be supposed, the strength of a joint is directly proportional to the number of nails in it. To prove this, various experiments were made (see Table VI), using a varying number of nails. In regard to the number of nails in a given area, experiments were made, with the following results: With 50 and 60-penny nails in 2$\frac{7}{8}$-inch pine, a distance of 1$\frac{1}{2}$ inches from the end and 1 inch from the edge was necessary to prevent splitting; in the case of a 6-penny nail and 1-inch board, it required the nail to be $\frac{3}{4}$ inch from the end and $\frac{1}{2}$ inch from the edge to prevent splitting. Where the boards and planks were not split by the driving of the nail they developed the full strength; in other words, the nail sustained as great a pressure as though it were in the center of the piece.

Experiments were made to determine the elastic limit and crushing strength of the woods used (Table VIII). We also made an attempt to determine the elastic limit, modulus of elasticity and ultimate strength of the wire nails, but without much success. Several nails were broken, but not until they had been crushed in the jaws of the machine. Those broken averaged 90,000 pounds per square inch.

TABLE VI. EFFECT OF NUMBER OF NAILS.

No. of Tests.	No. of Nails in Joint.	Size of Nails.	Timber.		Elastic Limit per Nail.			Max. Load per Nail.			Extension under Max. load inches.	Return Unloaded inches.
			Through.	Into.	Max.	Min.	Mean.	Max.	Min.	Mean.		
1	2	6d.	1 in. W. P.	N. P.			80			155	¼	$\frac{1}{16}$
1	3	"	" "	"			57			163	⅜	$\frac{1}{16}$
1	4	"	" "	"			50			156	⅜	$\frac{1}{16}$
1	5	"	" "	"			40			165		
2	2 & 3	20d.	1⅞ in. W. P.	"	233	225	229	455	433	444		
5	2 to 10	"	2⅛ in. N. P.	"	250	180	214	500	425	476	⅜	$\frac{1}{16}$ to ⅛
4	2 to 10	30d.	2⅛ in. " "	"	250	183	208	560	450	508	¼ to ⅜	$\frac{1}{16}$ to $\frac{3}{32}$
1	2	50d.	$2\frac{13}{16}$ in. W. P.	W. P.			305			795	½	$\frac{1}{16}$
1	4	"	" "	"			262			715	"	$\frac{1}{16}$
1	6	"	" "	"			333			750	"	$\frac{3}{32}$
1	9	"	" "	"			294			790	"	$\frac{1}{16}$
5	2 to 10	"	2⅞ in. N. P.	N. P.	450	320	375	960	700	854	½ to ¾	
4	2 to 6	60d.	$2\frac{13}{16}$ in. W. P.	W. P.	366	316	340	852	783	822	⅜ to ½	$\frac{1}{16}$ to ⅛
1	2	"	2⅞ in. N. P.	N. P.			350			815	½	
*1	3	"	" "	"			440			900	⅜	
1	4	"	" "	"			350			884	½	⅛
1	5	"	" "	"			380			930	⅝	
1	6	"	" "	"			383			1000	⅝	⅛
1	10	"	" "	"			380			970	⅝	
†1	10	"	" "	"			315			850	¼	
‡1	13	"	" "	"			346			723	½	

*Nail 1 inch from edge and 1½ inches from end of plank.
†Top piece slightly split before test. Nails 2 inches from end of plank.
‡Lower block slightly split before test.
These two last tests were taken at a time previous to the others in the serie.

TABLE VII.

Loads at different extensions through oak plank into oak block.

No. of Tests.	Nails.	Plank.	Average Load at Extension of—							
			0	1/8	1/4	3/8	1/2	5/8	3/4	7/8
5	1-20d. wire	2″	548	842	1126	1234	1366	1402	1408	1382
*5	1-20d. "	2″	528	792	994	1060	1122	1196	1252	1262
†4	1-30d. "	2″	578	913	1130	1193	1298	1378	1435	1478
‡4	1-40d. "	2″	683	1075	1380	1540	1595	1700	1793	1843
§2	1-60d. "	3″	715	1335	1690	1830	1890	2025	2085	

* Holes drilled with No. 15 drill, diameter = 0.177 inch.

† Holes drilled. Diameter of hole = 0.80 diameter of nail.

‡ Holes drilled. Diameter of hole = 0.200 inch.

§ Holes drilled. Diameter of hole = 0.211 inch.

TABLE VIII.

Crushing strengths of woods used—2-inch cubes with blocks whose length was four times the diameter; the elastic limit was approximately equal to the ultimate strength.

Wood	No. of Tests.	Crushing Load per Square Inch. Max.	Min.	Mean.
White pine	4	5125	4500	4844
Norway pine	3	6100	5625	5825
Oak	4	6825	6387	6603

In the light of these few experiments, it is rather difficult to say just what factor of safety should be used. The value given to each nail must undoubtedly be under the elastic limit. Possibly the results given above will aid in arriving at some definite ideas along this line.

DISCUSSION.

MR. K. E. HILGARD.—The daily newspapers report frequently the failures of grand stands, speakers' platforms and builders' scaffolds, which cause panic and too often the loss of human lives. These occurrences must necessarily reflect on the carelessness or incompetency and ignorance of builders and those who may have previously passed on the safety of such structures. The experiments brought before us, under a title which might possibly be attacked as a misnomer, tend to fill a vacancy and to supply knowledge in a direction in which, so far, decision has mostly been based upon practical judgment or rough guesswork. The average practicing builder, and even the engineer, is perhaps not afforded opportunity nor prepared to make tests or experiments for the purpose of increasing his knowledge. He must rely on precedents, and he is fortunate indeed if he can turn to some institution of learning and find some ambitious aspirant

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to the profession ready to carry on investigation under practical guidance. The results before us, although not satisfying, are at least gratifying. All who have had occasion to make use of nailed or spiked joints in actual practice or mere design will fully appreciate the importance of the subject. While the character of the structures just mentioned is usually temporary, there are many cases, even in highway and railway bridges, where joints held by nails or spikes are called upon to transmit loads or strains for years and years and under greatly varying conditions. In view of this fact, it is much to be desired that the series of experiments be extended to cover a greater variety of timber used in construction, and to observe the results of repeatedly (suddenly or slowly) applied and released loads; the effect of age of joint in various stages of seasoning of the timber; the effect of water-soaking (once or repeated) of pieces joined, and possibly the effect of extreme temperatures. Like other conclusions to be drawn from experiments, they must be based on a great number of the latter in order to be of practical value. From the description of the manner of testing, it would appear that in the case of the blocks for which the clamps were not used the bending movement due to eccentric application of load was not entirely eliminated. However, results from tests including eccentric application of load properly analyzed and classified might prove fully as valuable, inasmuch as few cases occur in actual practice which are free from such a condition. The necessity of altering or elaborating the formulæ so far derived would undoubtedly appear, in order to cover a larger scope of practical utility. While the experiments can, therefore, not be considered to cover the question, they are decidedly interesting, meritorious and worthy of encouragement by the profession.

Mr. A. W. Muenster.—These records of experiments on the shearing strength of nailed wooden joints by Messrs. Walker and Cross will be received, I believe, with general interest by engineers.

Some years ago I commenced to look for data in regard to the shearing strength of nails in wood, and was very much surprised to find that practically no investigation had been made on this subject, which I considered one of some importance, and I wish to thank the gentlemen who have presented the above paper to our Society for their interesting work. Considering the limited time at their disposal, the main points within the given range of these experiments are very well covered. Future tests must determine the causes of differences, other than the obvious ones,

between parallel experiments. That these differences should be considerable was only to be expected where one of the materials of the composition—wood—is known to be of variable quality, not only within the same species and the same log, but within the same specimen at different degrees of seasoning. If I am not mistaken, the last condition will account for some of the greatest variations in the tests, and it is very desirable, if the experiments can be continued—as I hope they will be—that attention should be paid to this point.

The influence of the degree of seasoning is shown best, perhaps, in comparing the different tests of the $5\frac{1}{2}$-inch and 6-inch nails.

The 3-inch and 4-inch planks used were, in the beginning, less thoroughly seasoned, presumably, than the thinner boards and planks used for the smaller nails, and the sustained loads were unexpectedly low in comparison. After several weeks the experiments were repeated, with the results shown in Table IV and in Table V. The materials used were, to all appearances, of the same quality as in the earlier tests of the same nails, but had, in the meantime, seasoned in a steam-heated room.

Another apparent cause of variation is the length of nail in the lower plank, a point that I shall refer to later.

In order to get immediately available results from the test for my own use, I have studied the experiments and tried to make some deductions.

The tests on the elastic limit and ultimate strength of the metal in the nails, and of the wooden specimens used in the experiments, were made for the purpose of discovering, if possible, some relation between these values and the shearing strength of the joint. On inspection of the test records, it is evident that some other quality in the wood than its resistance to compression in direction of the fibers determines the shearing value of the nail in it. While the tests of Norway pine show an ultimate crushing strength about 21 per cent. greater than that of white pine, there is practically no difference between the shearing of nails in either. The oak, with only about 36 per cent. crushing strength greater than that of white pine, gave a shearing value for the nail greater by from 110 to 130 per cent. This great difference is, no doubt, caused by the difference in structure between the woods. The pines are built up of alternate layers of hard and soft wood, permitting the fibers to yield more easily than the homogeneous fibers of the oak. That it is the quality of this soft fiber in the pines that largely determines the resistance is borne out also by

the statement of the authors that the nails seemed to have the same value whether strained along or across the fiber, and still farther evidenced by the slight difference shown by the nails in sap-wood. (See Table IV.) It will be necessary to establish a coefficient for each kind of wood by actual experiment.

The bend in the nails, after ultimate tests, shows great regularity in length and form. A number of measurements of these bends would seem to show a fairly constant relation between the diameter of the nail and the length of the bend, and this may be of some assistance in the construction of a formula giving the amount of resistance.

The experiments with the shortened 50-penny and 60-penny nails (see specimen No. 183, Fig. 3) show that, in order to get the full strength of the joint, the point of the nail should extend far enough into the under plank to prevent any sideway movement of the nail point and to develop the double bend in the nail, and that this will require a minimum length of from 10 to 12 diameters for white and Norway pine, less for the harder woods, and correspondingly more for softer and more porous timber.

The lack of this proportion will, I think, account for some tests considerably below the expected average.

Evidently the strength of this composite joint is made up of a good many elements—of the qualities, dimensions and relative arrangement of the materials—and it will take a much larger number of experiments and observations to discover the true relation of these elements.

However, in order to make the present experiments available for use, it is desirable to formulate some empirical expression that will give values for the varying diameters adopted by the different nail manufacturers, and that will conform approximately to the averages of the tests.

The formula Cd^2, where d = diameter of nail in inches and C a coefficient derived from the experiment, would seem to follow the test values fairly well. For the point that we may call the elastic limit of the joint, for want of a better expression, the coefficient would be about 5500 for the white and Norway pine, varying probably from 4000 for green sap timber to about 6500 for thoroughly seasoned wood. The experiments on the oak timber show clearly how the hardness of the timber affects the strength of the joint, but is, I should judge, considerably above the average, as the oak was thoroughly seasoned and so hard that it was impossible to drive into it any nail above 20-penny size without first drilling a hole.

The coefficient for oak, as deduced from the few experiments, would be 13,500 for the elastic limit.

The following table gives the experimental value of the elastic limit averaged from all the tests, and also the corresponding values obtained by the formula suggested above:

Nails.	Length.	Diam.	Experimental Elastic Limit. Pounds.	Elastic Limit by formula $5500 \times d^2$. Pounds.
6d.	2″	0.11	55	67
8d.	2½″	0.128	88	90
10d.	3″	0.152	112	127
16d.	3½″	0.148	112	120
20d.	4″	0.197	218	212
30d.	4½″	0.205	226	231
40d.	5″	0.226	275	280
50d.	5½″	0.243	342	324
60d.	6″	0.261	362	373
80d.	7″	0.303	500	506

The tests show what might indeed be expected—that in a joint containing 10 or more nails each nail may be reckoned at its full value, and, what is of special practical importance, that 6-inch nails may be spaced $1\frac{1}{8}$ inches *c* to *c*, or about 4 diameters, and within the same distance to edge of timber, without impairing the strength of the joint. For the smaller nails this distance could presumably be reduced in proportion to the diameter.

The time test shows that there would be a certain extension of the joint under the load, called the elastic limit, after sufficient lapse of time, but this movement would probably not exceed 1-40 to 1-20 inch, and could hardly be considered of any moment in ordinary wooden construction.

What shall be considered allowable stress on such a nail joint will, of course, depend on the more or less temporary character of the structure, but from 60 to 80 per cent. of the elastic limit, it seems to me, would be a safe load.

It is highly desirable that these tests should be continued, and the experiments extended to other structural timber and to the larger sizes of wire nails, say from 7-inch to 10-inch.

BRADLEY & POATES, ENGR'S N.Y

Association of Engineering Societies.

Vol. XIX. JULY, 1897. No. 1.

PROCEEDINGS.

Boston Society of Civil Engineers.

May 19, 1897.—A regular meeting of the Society was held at Chipman Hall, Tremont Temple, Boston, at 8 P.M. Ninety-eight members and visitors present.

President Dexter Brackett, on assuming the chair, thanked the members for the honor conferred upon him in electing him to the presidency for the coming year.

The record of the last meeting of the Society was read and approved.

Messrs. Frank B. Bourne, Ernest W. Branch, Ralph H. Chambers, Francis A. Dennette, John O. De Wolf, Charles H. Gannett, Herbert L. Ripley, Ernest W. Wiggin, and Herbert A. Wilson were elected members of the Society.

The Secretary read a short paper by Mr. Clemens Herschel, giving the history of the origin of the Chézy Formula for the flow of water in channels and conduits. A brief discussion of the paper by Mr. E. B. Weston was also read.

Mr. A. Lawrence Rotch, director of the Blue Hill Meteorological Observatory, was then introduced and read a very entertaining paper, entitled "An Account of the Meteorological Investigations in the Upper Air made at the Blue Hill Observatory." The paper was supplemented by a series of beautiful lantern slides showing the principal meteorological observatories of the world and the apparatus used at the Blue Hill Observatory.

The thanks of the Society were voted to Mr. Rotch for his interesting paper, and to him and Mr. H. H. Clayton for courtesies shown the members this afternoon during the visit to the Blue Hill Observatory.

Adjourned.

S. E. Tinkham, *Secretary.*

Civil Engineers' Club of Cleveland.

July 13, 1897.—Meeting of the Civil Engineers' Club of Cleveland, in the rooms of the Club, Case Library Building, Tuesday evening, July 13, 1897, President Ritchie in the chair.

Present, thirty-one members and six visitors.

The minutes of the last meeting were read and approved.

Charles O. Palmer and August A. Honsberg were appointed tellers to canvass the ballots for the election of new members.

The Executive Board reported the approval for active membership of Charles Warren Comstock and John William Easton.

Mr. William H. Searles reported as chairman of the Committee on Arrangements for meeting the excursion of the Ohio Institute of Mining Engineers, which took place on the 16th, 17th, and 18th of June.

Dr. Langley being absent, Mr. F. A. Coburn reported for the Committee on Annual Outing.

Mr. William E. Reed presented the paper of the evening, entitled "The 40-inch Equatorial of the Yerkes Observatory."

It was a very complete description of the great telescope and the observatory in which it is mounted, illustrated by half-tones from photographs taken during the erection and of the completed structure. An interesting discussion followed, in which Dr. Dayton C. Miller, W. R. Warner, and others took part.

Messrs. George Isaac Allen, William Sanford Bidle, Lord Mortimer Coe, John Nash Coffin, Charles Ithamar Dailey, Ernest Winfield Hulet, Arthur Cameron Johnston, Francis Henry Prentiss, William Emerson Schroeder, George Edgar Titcomb, and Rollin Henry White were reported as elected to active membership.

On motion, it was voted to adjourn to the September meeting.

After the meeting a light lunch was served.

F. A. Coburn, *Secretary.*

Detroit Engineering Society.

Detroit, Mich., July 23, 1897.—The regular monthly meeting was held at the Hotel Ste. Clair, Vice-President Alex. Dow presiding, and twenty-two members and two visitors present. The Executive Committee reporting favorably upon the application of A. B. Raymond, he was elected to resident membership. The same committee announced that the August meeting would be omitted, in accordance with a recommendation of the President, and noticed a by-law relating to dues of members joining the Society during the last half of the year, to be voted upon at the next regular meeting. The Executive Committee further reported that the Library Committee had submitted its report, and recommended that the work be continued by a committee of three. Upon resolution, the report of the Executive Committee was adopted, and the following committee was announced: Mr. Willard Pope, chairman, and Messrs. George Mattsson and Henry E. Whitaker. Five applications for resident membership were received and referred to the Executive Committee. The Secretary read a letter from United States Senator James McMillan, acknowledging the receipt of resolutions of the Society relative to the duty on foreign scientific works, and promising consideration of the same.

The Society then listened to a talk by Mr. George Y. Wisner on "Economical Engineering Construction," being a description of river and harbor improvement work on the Mississippi river and the Gulf of Mexico,

which led to a discussion, participated in by Messrs. Dow, Cooley, Dunlap, Williams, Keep, Hitchcock, and Wisner.

Adjourned.

GARDNER S. WILLIAMS, *Secretary.*

Montana Society of Engineers.

A SPECIAL MEETING of the Society was held in the G. A. R. Hall, in Helena, on June 26, 1897, to which the public was invited. The hall was well filled with an appreciative audience At 8.30 P.M. Mr. F. L. Sizer, chairman of the evening, announced Prof. L. S. Griswold, who would deliver a lecture upon the "Geology of Helena and Vicinity." Professor Griswold has spent the past year in examining and classifying the formations in the vicinity of Helena, and his work has been very thorough and complete. Specimens of different geological formations were shown the audience during the lecture. The lecture was illustrated by charts and lasted about one hour, after which Mr. R. H. Chapman, of the United States Geological Survey, was introduced, who delivered a short address upon what that department has done and is doing in Montana. The first surveys were made in 1882, and 16 sheets have been published, embracing 38,000 square miles. A party is now outfitting in Helena, which will extend the system of triangulations, after which topographical surveys will be made. Five parties will be placed in the field in different parts of the state. Mr. Walter H. Weed, United States Geologist, is now in the state and will remain during the season, engaged in geological work.

After the lectures a short business session was held, Mr. Finlay McRae presiding. Peter C. Kettle, of Belt; George R. Metlen, of Dillon, and Arthur W. Warwick, of Wickes, were elected members.

There were five applications for membership, which were favorably considered, as follows: Messrs. Frank Beach, S. H. Crookes, E. C. Kinney, A. L. Dean, and W. H. Williams. A unanimous vote of thanks was extended to the speakers of the evening.

A. S. HOVEY, *Secretary.*

THE regular monthly meeting of the Society was held in the office of Hovey & Bickel, in the Merchants' National Bank Building, Helena, July 10, 1897. Mr. F. L. Sizer was elected chairman for the evening. The minutes of the last meeting were read and approved, after which Messrs. Keerl and Taylor were appointed tellers to canvass the letter ballots. There were 30 ballots, all affirmative, and the President announced the following-named gentlemen elected members, viz: Profs. Frank Beach and W. H. Williams, of the State Agricultural College at Bozeman; Mr. S. H. Crooks, county surveyor of Park county; Mr. A. L. Dean, superintendent of the United Smelting and Refining Company, and Mr. Edward C. Kinney, civil engineer, residing at Manhattan, Mont.

Resolutions were passed that the members just elected and others that may be elected during the latter half of the present year be required to pay only semi-annual dues, in addition to the usual entrance fee of $5, and that they receive the JOURNAL OF THE ASSOCIATION for only the latter half of the year at the Society's expense, but if the Secretary is immediately notified he will order back numbers from the beginning of the year at the

additional charge to the member of $1.50. The Society, through the courtesy of Mr. John F. Davies, librarian of the Butte Free Public Library, is the recipient of a special index containing a list of books pertaining to engineering and architecture on file in said library. This list was prepared at the request of the Society at considerable labor by the librarian. The list shows 689 volumes of books upon engineering. Members of the Society in Butte were consulted and assisted in making the selection. The library doubtless has as choice and valuable selection of technical books upon this subject as any library in the West—in fact, as can be found in many of the large Eastern cities.

The Society tendered a vote of thanks to Mr. J. F. Davies.

Mr. Titus Ulke, of the United States Geological and Topographical Survey, gave a brief description of the work commenced and what is to be done during the present season in his department.

The Secretary was directed to make arrangements for an address by Mr. Louis Miller and an exhibition of his current water-wheel, a recent invention, which is attracting considerable attention. It was suggested that the Ten-Mile Creek, near the Broadwater Hotel and Natatorium, would be a good site for the exhibition.

Members are urgently requested to forward to the Secretary, to be placed on file, all articles pertaining to county surveyors or road legislation, or other engineering matters which may appear in the newspapers of the State, thus calling attention to matters which may be of importance and which otherwise would be frequently overlooked.

A. S. Hovey, *Secretary.*

Summer Excursion of the Engineers' Club of St. Louis.

On the afternoon of Saturday, July 17, 1897, the Engineers' Club of St. Louis, through the kindness of Mr. J. A. Ockerson, was invited to an excursion down the river to inspect the new Government dredge-boats now being tested at the lower end of the city. The steamer "Mississippi," with about seventy-five members of the Club on board, left her wharf shortly after 12 o'clock and proceeded down stream toward the point where the dredge-boats were operating. Immediately after leaving a delightful lunch was served. A stop was first made at the dredges "Alpha" and "Beta," which are now undergoing repairs on the west bank of the river. The general principle upon which all of these dredges operate is that of the centrifugal pump. The sand in front of the boats is first stirred up by water-jets, scrapers, or cutters into a sludge, and then pumped by a centrifugal pump through the boat and into a pipe leading from the rear end of the boat. This pipe is floated between pontoons, and may be adjusted to deliver the discharge at any desired point. The principle of the centrifugal pump is the essential one in all of the dredges, although they differ quite widely as to the details of the machinery. The "Alpha" was the first of these boats to be built. The "Beta" was the second, and is the largest dredge-boat ever constructed. It was guaranteed by the builders to have a capacity to handle 2400 cubic yards of sand per hour, but on test it handled 7400 cubic yards in this time.

After these dredges had been inspected the "Mississippi" steamed to

the other side of the river, where the "Gamma" and "Delta" are now making their endurance test. Here the practical operation of the dredges was illustrated. The suction pipe was raised, and the methods of handling the different machines and the plans for anchoring the boat and for feeding the suction pipe forward were shown. One of these boats uses jets of water for stirring up the sand, and the other uses a revolving scraper.

A stop was next made at the snag-boats "Macomb" and "Wright," where methods for removing snags from the river bed were illustrated.

The day was an ideal one, and all who were fortunate enough to be on the steamer "Mississippi" thoroughly enjoyed the excursion. A vote of thanks to Mr. J. A. Ockerson, the host, was carried by a unanimous vote.

Richard McCulloch, *Secretary.*

BRADLEY & POATES, ENGR'S N.Y.

Association of Engineering Societies.

Vol. XIX. **August, 1897.** No. 2.

PROCEEDINGS.

Boston Society of Civil Engineers.

June 16, 1897.—A regular meeting of the Society was held at Chipman Hall, Tremont Temple, Boston, at 8 o'clock, P.M. President Dexter Brackett in the chair. Eighty members and visitors, including ladies, present.

The record of the last meeting was read and approved.

Messrs. George B. Francis and Alpheus M. Johnson were elected members of the Society.

The thanks of the Society were voted to the officials of the Boston and Maine Railroad for the courtesies extended by them to the members taking part in the excursion to the Middlesex Falls this afternoon.

Prof. C. Frank Allen then read the paper of the evening, entitled "Railroads: Their Development and Methods of Location." The paper was very fully illustrated by lantern slides, showing early as well as modern types of locomotives and cars, types of rails and rail-joints and railroad locations in this country and abroad.

Adjourned.

S. E. Tinkham, *Secretary.*

Technical Society of the Pacific Coast.

San Francisco, Cal., August 6, 1897.—Regular meeting called to order at 8.30 P.M. by Past President Richards.

The minutes of the last regular meeting were read and approved.

Mr. George D. Blood, mining engineer, of Iowa Hill, Placer Co., California, was declared elected after a count of ballots.

The paper presented by Mr. James D. Schuyler and read at the June meeting by the Secretary, entitled "The Construction of the Hemet Dam," was reviewed by Mr. C. E. Grunsky and opened for a general discussion, which took up the evening.

It was moved and seconded that the Executive Committee be instructed to communicate with Professor Frank Soulé and to request him to obtain from the Board of Regents of the University of California the privilege of preparing all the available data of his college on Pacific Coast

Timber Tests into a paper, to be read before the Society and published with its transactions. Carried.

The Secretary thereupon read the reprint of a report by City Engineer Dockweiler, of Los Angeles, on the deterioration of the iron, cement, and brick work in the Outfall Sewer System of that city, caused by the accumulation of sulphuretted hydrogen gas in the sewer.

The Secretary was instructed to write to Mr. Dockweiler and to obtain from him further information and more of the facts and data regarding these ravages.

An excursion to Mt. Tamalpais having been planned by the Executive Committee, it was agreed that the committee appointed to arrange this outing have further time and report to the Directors any adopted plan for the purpose.

Adjourned.

Otto von Geldern, *Secretary.*

Association of Engineering Societies.

Vol. XIX. | September, 1897. | No. 3.

PROCEEDINGS.

Montana Society of Engineers.

In view of resolutions passed by the Society, March 13, 1897, a special meeting, to which all the county surveyors and county commissioners of the state had been invited, was held in the court house of Lewis and Clarke county, at Helena, March 30, 1897. John W. Wade, county surveyor of Lewis and Clarke county, called the meeting to order at 10 A.M.

ADDRESS BY JOHN W. WADE.

"The State Legislature, just adjourned, has given great prominence to the road problem by enacting laws radically changing almost every feature of previous regulations as to the maintenance of roads, and by this new departure county surveyors are now entrusted with the care of the entire system of wagon roads in the state.

"The average engineer may well fear the result of over-engineering, for it will be a very easy and natural mistake to apply too rigidly the principles of engineering to the maintenance of public highways; this is especially true of Montana at present because of the crude condition of our roads from an engineering standpoint. On the other hand, there is danger that, having found it impracticable, if not impossible, to use mathematical precision in many problems that will confront us, and despairing of ever securing professional order in the field and in the office, we will pigeon-hole our professional knowledge and 'go it by rule of thumb,' as road supervisors have done before us, with this difference, possibly, that we will use less common-sense.

"I think it can be easily shown that our greatest trouble,—to prove this law is a wise one,—will be in these first years; for after the grades and alignments are once fixed and approved by the county commissioners it will be but the work of a few years to cut and fill to the grades adopted and to make the necessary changes in the location of the road itself.

"We are to decide in many, very many, instances whether for all time the public shall be compelled to go hundreds of yards in extra travel—and miles, it may be—in order to preserve intact Mr. Johnson's calf pasture, or Mr. Bilkin's pig pen or potato patch, or whether it were better to

recommend at once condemnation of some small enclosure, or a large one if need be, in order that a road may be placed for the convenience of the public where it rightfully belongs.

"We are to use our knowledge of the general topography of the state in the matter of fixing the position and general direction of the principal roads, having regard to the coincidence of the same from county to county, so that finally our great state shall have what nature fitted her for,—the grandest system of roads in America.

"In many other states there is great difficulty in the matter of drainage, because of the flatness of the general surface; we have difficulty here in this thing only because of the ignorance of the average road builder. It is no fault of the topography.

"In other states also much difficulty is experienced in the matter of surface material, because of the unsuitableness of the average soil for road-beds. We have difficulty on the same line only because the average road builder seems not to have seen that almost any class of earth or other material in Montana will make a good road if only it be properly surfaced and drained.

"I suggest for your thought and discussion the following topics, that if their importance shall warrant they may be given to the proper committee or otherwise be brought before the convention, as shall seem wisest to you:

"(1.) Organization and order of business. (2.) Blanks to conform to the new laws. (3) Road oversight. (4.) Apportionment of work, with reference to county as a whole. (5.) Road machinery—what will be most economical and effectual implements? (6.) Matter of records—what is the best form of notes and plat?"

Hon. Fred Whiteside then took the chair and Paul S. A. Bickel acted as secretary.

Preliminary to the work of the convention the Chairman appointed the following committees:

Organization—H. B. Davis, F. H. Ray, Lewis Penwell, E. Beach, E. M. Wardwell, Ed. S. Bond, J. W. Wade.

Blanks to Conform to New Laws—Lewis Penwell, H. S. Hyatt, A. L. Jaqueth, J. W. Wade, Lee Word.

Manner of Utilizing Road-tax Workers—J. Larson, H. C. Freeman, William H. Risk.

Road Oversight and Information—Albert S. Hovey, H. B. Davis, Charles Helmick.

Apportionment of Road Work—William Muth, A. L. Jaqueth, A. E. Cumming.

Road Machinery—J. W. Wade, H. B. Davis, H. C. Freeman.

Plats and Records—J. S. Keerl, Finlay McRae, T. T. Baker.

Grades and Drains—H. B. Davis, A. L. Jaqueth, George K. Reeder.

Surveyor' Accounts with County—Keerl, Benjamin, Hyatt.

Legislation—Lewis Penwell, George Bruffy, Lee Word, F. H. Ray, J. S. Keerl.

The appointment of the committees completed the work of the morning, and an adjournment was taken until 2 P.M.

At 2 P.M. the meeting was called to order by A. E. Cumming, chair-

man; A. S. Hovey, secretary. A programme was laid out for the evening session, which was to be the most important of the convention. There was some informal discussion, but the principal topics were laid over until evening.

The Secretary reviewed the proceedings of the Montana Society of Engineers in the matter of county surveyors and road laws. This matter was first taken up by the Society at its annual meeting on January 14, 1893, at which time, on motion of Mr. J. S. Keerl, a committee of three, consisting of Messrs. Wheeler, Page, and Jones, was appointed to prepare a memorial to present to the Legislature, and to draft suitable bills regulating the compensation of county surveyors. The bill was not prepared in time for presentation to the Legislature during that session. The matter was again resumed by the Society, on October 13, 1894, and, through the untiring efforts of Messrs. E. R. McNeill, F. P. Gutelius, and Mr. Ray, of the Good Roads Association, House Bills Nos. 356 and 124 were finally passed by the Legislature in 1895. These bills, however, were very dissimilar to the bills as originally framed by the Society. The proceedings mentioned are printed in the Journal of the Association of Engineering Societies, vol. xii, pages 108, 169, 276; vol. xiii, pages 100, 115; vol. xiv, pages 9, 13, 37, 64, 67.

At the annual meeting of the Society, held at Great Falls, January 9, 1897, it was considered advisable for the Society to make another effort to obtain proper legislation upon the Road Laws and County Surveyors' bill, and a committee of six was appointed, as follows: T. T. Baker, E. R. McNeill, P. S. A. Bickel, C. M. Thorpe, A. W. Mahon, and H. B. Davis, all being county surveyors except Mr. Bickel, an ex-county surveyor just retired. Through the efforts of this committee, House Bill No. 266, defining the powers and duties of county surveyors, and abolishing the office of road supervisor, was passed. (This bill was published in full in the Journal, in vol. xviii, Proceedings, page 44.) House Bill No. 280, relating to the levy, collection, and disposition of road-taxes, was also passed. Both bills were passed substantially as framed by the Society, except House Bill No. 266, which changed the salary clause by making it the limit to be allowed the county surveyor in the different class counties, allowing the county surveyor a per diem of $5, and cutting off any provision for the payment of actual traveling expenses. The laws were passed to take effect as soon as passed. The Constitution of the state provides that no salary or emolument of a county official shall be changed during his term of office. According to good legal authority, the original per diem of $7 will hold during the present term, but in the next term of office the new law will take effect, viz: $5 per day, without allowance for traveling expenses. In many instances a single county in this state is larger than some of the Eastern States, and the traveling expenses will be frequently larger than the per diem. The future county surveyor will be obliged to devote his time, for the improvement of his county, for almost no compensation.

In view of complications, already commencing, the Society advised a convention of the county surveyors. After considerable discussion, the meeting adjourned to meet in Court Room No. 1 of the District Court, at 8 P.M.

EVENING SESSION.

The meeting was called to order at 8 P.M., March 30, Mr. Frederick Whiteside in the chair; Paul S. A. Bickel, secretary.

The meeting was an open one for all interested in the subject of good roads, and, as in the morning session, a number of well-known Helena wheelmen were present. Among the county officials present were two commissioners from Silver Bow county, two from Lewis and Clarke, and several others, including the full board from Broadwater county.

House Bill No. 280 was read, as follows:

HOUSE BILL NO. 280.

An act amending Sections 2640, 2642, 2643, 2680 of the Political Code, relating to the levy, collection, and disposition of road-taxes.

Be it enacted by the Legislative Assembly of the state of Montana:

SECTION 1. Section 2640 of the Political Code is hereby amended so as to read as follows: Section 2640. There must be levied out and collected on all taxable property in the county not less than one mill nor more than two mills on the dollar for road purposes; also a special road-tax of $3 on each able-bodied man over the age of twenty-one years, and under the age of forty-five years, residing in each road district, provided that any person liable for said special road-tax may elect to perform one day's labor, either in person or by another, on the public roads, under the proper officer as herein provided, in lieu of the payment of the said $3. Said special road-tax shall be due and payable to the county assessor after October the 1st of each year, unless one day's labor of eight hours has been performed in lieu thereof, as provided by law; and the county assessor shall collect such special road-tax on or before December the 1st of each year, in the manner provided by law, providing for the collection of poll-tax. All special road-taxes collected by him must be paid to the county treasurer monthly, and be placed to the credit of the county road fund of the road districts in which the same is collected. The county surveyor of each district shall, on or before the first day of October of each year, deliver or mail to the county assessor a list of the names of all male persons in each road district who are required to work said special road-tax for the year and who have failed to work out the same. Any person whose special road-tax is unworked by October the 1st of each year shall pay $3 to the assessor, as provided by law.

SEC. 2. Section 2642 is hereby amended so as to read as follows: Section 2642. Every person liable for said special road-tax who performs in person the one day's labor in lieu thereof shall receive a receipt for the sum of $3, signed by the county surveyor, which shall be a sufficient receipt for said special road-tax.

SEC. 3. Section 2680 is hereby amended so as to read as follows: Section 2680. If any person required to pay the special road-tax mentioned in preceding sections of this chapter has no property subject to taxation, and does not elect to work out said special tax as therein provided, the county assessor must collect the same at the time of making the assessment. If it be not paid at the time, and the person owing the same is in the employment of any other person, the assessor must deliver to the employer a written notice, stating the amount of tax owing by such employe (naming him), and from the time of receiving such notice said

employer is liable to pay said tax, provided that any money is then due or shall become due such employe from each employer before the time for the payment of general taxes, and the employer may deduct the same from any amount so due each employe.

SEC. 4. All acts and parts of acts in conflict with this act are hereby repealed.

Approved March 4, 1897, at 6.50 o'clock P.M.

ROBERT B. SMITH, *Governor*.

House Bill No. 266 (published in full in JOURNAL, vol. xviii, page 44) was then read.

Mr. Lewis Penwell, chairman of the Committee on Blanks to Conform to the New Law, introduced the following blanks: Order for supplies, receipt for road-tax work, affidavit of posting.

A paper from M. S. Parker, of Great Falls, entitled "The New Road Law of Montana," was then read and discussed.

Hon. Lewis Penwell, attorney-at-law, chairman of the Committee on Legislation, submitted the following opinion:

"If the new law, so far as compensation is concerned, is sustained by the courts, all county surveyors will receive $5 per day, up to the maximum, for all work performed, whether the said work is of a professional nature or upon roads. There is, however, a very serious doubt as to whether the new law, as regards compensation, can be sustained. The office of the county surveyor is a constitutional office, and accordingly the compensation of the incumbent of this office cannot be increased or diminished during his term of office. The duties, however, can be increased. At the time these county surveyors were elected the law stated that they should be paid for professional work only; the new law provides that they shall be paid for other work, thus altering their compensation after they have been elected to office. If this view of the matter were sustained by the courts, they would be entitled to $7 per day for professional services rendered under the old law, and would be required to perform the additional services imposed upon them by the new law, but without any additional compensation. This is the view now held by Attorney-General Nolan. Probably the way the matter stands now, if he were called upon by some board of county commissioners within this state for a ruling as to whether or not they would allow compensation to county surveyors for road work, he would hold that the said county surveyors were not entitled thereto. His suggestion is that such steps be taken as may be necessary to bring the matter before the courts immediately, and get the same finally disposed of.

"I will state further that Mr. Sanders and myself have given the matter some little consideration, and are constrained to differ with the Attorney-General, and believe that if the matter were taken into the courts it would be finally decided that the present county surveyors would be entitled to $5 per day, up to the maximum, for all services rendered, whether professional or otherwise."

By request of Mr. Beach, Section 2759 of the Political Code was read.

It was decided to bring the question before the courts, if possible. J. S. Keerl, chairman of the Committee on Surveyors' Accounts with County, submitted the following report, which was adopted:

"The question of the location and construction of highway roads, in our opinion, should be surrounded by the same general features and considerations which govern the location, construction, and maintenance of railroads. The question of proper location should be governed by topographic features, and desirable alignment and grades and the stability of construction, which, co-related, have their bearings, should be recognized the same as upon railroad location and construction. With these views, we believe that to properly locate, construct, and maintain our public highways an organization should be perfected somewhat similar, or at least based upon those principles which surround the construction of railroads and other similar engineering works. The new law (which is entitled House bill No. 266,) passed by the Fifth Legislative Assembly of Montana, to be properly enforced and carried to a successful conclusion, we believe, should recognize the county surveyor as occupying a position similar to that of division engineer in charge of 100 miles of line upon a railroad construction, and that the road managers, which he will appoint, and as provided by the bill, fill a relative position to that of resident engineers upon railroad construction, who have charge of (say) 10 miles of line, and that, carrying forward the comparison, the resident engineers reporting to the division engineer all estimates, accounts, requisitions, etc., and the road managers reporting to the county surveyor, and thus recognizing that the county surveyor's office is the headquarters of the system which receives, collects, and distributes all information relative to the laying out, construction, and maintenance of the public highways. With these accounts, data, etc., and thus centrally located, the county surveyor is placed in a position where he can fittingly and thoroughly submit his report to the board of county commissioners, which board fills a position similar to that of the chief engineer of a railroad or its board of directors.

"Your committee have interpreted their duties as merely applying to suggesting a method of accounts, and not as regards detailing what accounts are necessary or in what form they should be presented, as they believe this would more properly belong to the 'Committee on Blanks to Conform to the New Law,' which report your honorable body have discussed fully."

The report of the committee was followed by an interesting discussion.

The Committee on Road Machinery, composed of J. W. Wade, H. C. Freeman, and H. B. Davis, recommended the use of improved road-making machinery wherever practicable. The committee believed that economy as well as improved roads would result from extensive and judicious use of machinery.

Mr. Wade stated that his county (Lewis and Clarke) had an Austin road machine, and that it would be used on all roads where it was practicable.

County Surveyor Thorpe.—The Austin machine makes the grade about 2½ feet above the bottom of the ditches, and we consider it a great saving of labor. We also use it largely for smoothing the grades.

County Surveyor Davis.—Three-fourths of the roads constructed by road supervisors in my county have no grades. The plowing has been done so near the wagon-tracks that the roadbed has to be filled in even before the freshets come.

County Surveyor Wade.—The advantage of this road machine is that it does not move any ground that is not put in the roadbed, and it leaves the waterways solid. It can be placed at such an angle as to plow 4 inches wide, or greater widths as desired. It has a swinging motion, and shaves off the earth.

Discussions by Messrs. Thorpe and Wardwell and others followed. Some of the speakers apparently did not favor the road machine.

Mr. Wardwell moved that a Committee upon Resolutions be appointed, and the chairman appointed Messrs. Muth, Wardwell, and Bradford, who presented the following resolutions:

Whereas, The new road law is very largely in the nature of an experiment; and

Whereas, Its provisions seek to obtain better results than under the old law, with the funds at the command of the different counties; and

Whereas, It is expedient that the law be given a full and fair trial; therefore be it

Resolved, That the county surveyors and boards of county commissioners of the different counties be called upon to use every endeavor to make a success of the said law by using special personal efforts to inaugurate a system of roads that will be a credit to each and every county and to the state, and to see that the funds of the counties are economically and judicially applied.

On motion of Mr. Wade, the convention adjourned until 2 o'clock P.M., March 31.

AFTERNOON SESSION.

The meeting was called to order at 2 P.M., Mr. F. Whiteside in the chair; Paul S. A. Bickel, secretary.

A discussion ensued upon plats and records, and the committee was given more time in which to report.

The county surveyors were unanimous in the opinion that all records and blanks should be uniform throughout their offices in Montana. The Committee on Blanks will not complete its work for several weeks.

A discussion on grades and drains, led by J. S. Keerl, of Helena, and E. M. Wardwell, was one of the most interesting features of the afternoon session. It practically ended the work of the convention, although, after adjournment, the sub-committee on plats, records, and blanks, consisting of Messrs. Paul S. A. Bickel, C. M. Thorpe, and T. T. Baker, J. S. Keerl, E. M. Wardwell, and others interested, met with the committee, which will report later to the Montana Society of Engineers.

The meeting was a successful one, and will, it is believed, result in better roads for the state.

It was moved and seconded that the Secretary use his influence to secure as full a publication as possible of the proceedings of the convention. Carried.

Mr. Keerl.—I move that a vote of thanks be tendered to the county commissioners for their kindness in opening to us the court room; also, to the president and other officers, who so patriotically performed their duties; also, to the press. Carried.

A motion to adjourn was carried.

A. S. Hovey, *Secretary*

The regular monthly meeting of the Society was held in the Merchants' National Bank Building, in Helena, on September 11, 1897. President C. W. Goodale arrived from his home in Butte just in time to call the meeting to order at the usual hour of 8 P.M. The fore part of the evening was devoted to business. Under the head of new business the President appointed Messrs. F. L. Sizer, of Helena, John Herron, of Marysville, and Elliott H. Wilson, of Butte, as a committee to nominate officers for the ensuing year. The Society voted to unite with the Society of Montana Pioneers in ordering from the Journal of the Association of Engineering Societies 500 copies of the memoirs of the late Col. de Lacy. The subjects discussed were mining operations, tunnel rights, and the action of mineral in the water of mines upon the pumps and pipes. Mr. Goodale stated that after a considerable amount of experimenting he has succeeded in partially obviating the difficulty by treating the water before entering the pipes.

Members will find a complete set of the Journal, all bound, in the Butte Public Library; also in the Helena Public Library, with the exception of Vol. No. 1, these libraries having obtained the early volumes by purchase. Three other libraries have incomplete sets. Mr. C. W. Goodale will endeavor to complete a set of the Journal for the School of Mines, at Butte. The Secretary's donation of Vol. No. 1 completes the Society's set. All are bound, five volumes having been bound recently. Messrs. Sizer and Neustadter have contributed Journals for filing in the public libraries.

A. S. Hovey, *Secretary.*

Technical Society of the Pacific Coast.

Regular Meeting, September 3, 1897.—Called to order at 8.30 P.M. by President Molera.

The minutes of the last regular meeting were read and approved.

Mr. John Richards, past-president, read the paper of the evening on the subject of "Hydraulic Rams," which was discussed.

Adjourned.

Otto von Geldern, *Secretary.*

Civil Engineers' Club of Cleveland.

Meeting of the Civil Engineers' Club of Cleveland, in the rooms of the Club, Case Library Building, Tuesday evening, September 14, 1897, President Ritchie in the chair. Present, 24 members and 3 visitors.

Secretary Coburn being absent, Mr. A. Lincoln Hyde was chosen secretary *pro tem.*

The minutes of the last meeting were read and approved.

Messrs. W. P. Brown and S. J. Baker were appointed tellers to canvass the ballots for the election of new members.

The Executive Board reported the approval for active membership of Messrs. H. E. Andrews and T. M. Brown.

The resignation of the vice-president, Mr. Clarence M. Barber, was read, and on motion it was voted that it be accepted.

A letter from Mrs. Royal Gurley was read by the president, and the following resolutions were offered by the committee appointed by the president:

As one by one we are called by the All-Wise Providence to relinquish our duties on this earth for those of promised peace and joy, so we now are called to mourn the death of our fellow-member, Royal Gurley, who, during his active lifetime, was connected with railroad work, mostly in the engineering department, and who, by his quiet, unobtrusive manner and upright dealing, was endeared to all his associates.

Resolved, That we extend to the bereaved widow and children of our deceased member our sincere and heartfelt sympathy.

Resolved, That this report and resolutions be placed upon the minutes of the Club and a copy of the same be sent to the widow of our deceased member.

Henry C. Thompson,
Aug. Mordecai,
James McIntyre,
Committee.

On motion, these resolutions were unanimously adopted.

James Ritchie, *President.*

Attest: A. Lincoln Hyde, *Secretary pro tem.*

Mr. William H. Searles read the paper of the evening on "The Consulting Engineer in Municipal Affairs." It was a very interesting paper, and called forth an unusually animated discussion, in which Messrs. Warner, Baker, Raynal, Johnston, Porter, McGeorge, and others took part.

Messrs. Charles Warren Comstock and John Wm. Easton were declared elected to active membership.

The meeting adjourned to partake of a light luncheon.

A. Lincoln Hyde, *Secretary pro tem.*

Engineers' Club of St. Louis.

457th Meeting, September 15, 1897.—The meeting was held at 1600 Lucas place, at 8.30 p.m., with President Flad in the chair. Seventeen members and two visitors were present.

The minutes of the 456th regular meeting and the minutes of the 239th, 240th, and 241st meetings of the Executive Committee were read and approved.

The Executive Committee reported that an offer had been received for a duplicate set of 21 volumes of the Transactions of the American Society of Civil Engineers, and recommended that the offer be accepted. This recommendation was adopted by the Club. On motion of Mr. Crosby, duly seconded, it was voted that the money received from the sale of these Transactions be applied to the library fund.

Mr. Charles W. Hawkes and Mr. Henry Branch were proposed for membership, and their applications were referred to the Executive Committee.

The Secretary read a communication from the Western Society of Engineers inviting the Engineers' Club of St. Louis to participate in its

excursion to Niagara and Philadelphia. The thanks of the Club were voted the Western Society of Engineers for this invitation.

Mr. S. Bent Russell then gave an informal talk on repairs which had been done on the conduit and settling basins of the water works. Cracks had appeared, due to settlement and temperature changes, and the methods which had been adopted for repairing these cracks were illustrated. Lantern slides showing the construction of the conduit and basins were exhibited. In the discussion which followed, Mr. Crosby described the methods which had been employed for measuring the distortion of the arch in the Sudberry conduit.

The president then exhibited some lantern slides showing the launching of the new dredge-boat "Zeta," which took place at Grafton, August 25.

There being no further business, the meeting adjourned to another room, where lunch was served.

RICHARD McCULLOCH, *Secretary.*

Detroit Engineering Society.

DETROIT, MICH., SEPT. 17, 1897.—Regular monthly meeting held at the Hotel Ste. Claire, Vice-President Keep presiding, and 20 members and 5 visitors in attendance. Among the latter, by invitation, were Major M. B. Adams, U. S. A. Engineer, 9th and 11th Lighthouse Districts, and Alfred Noble, C. E., member Deep Waterways Engineer Commission.

On recommendation of the Executive Committee, Messrs. Joseph De Gurse, David Maxwell, Gouverneur Morris, George Parks, and George F. Parker were elected to resident membership.

The Society then listened to a paper by Mr. Frank M. Dunlap, on "The Machinery of the Poe Lock of the Ste. Mary's Falls Canal," at the close of which an extensive discussion was participated in by the members and visitors present.

Adjourned.

GARDNER S. WILLIAMS, *Secretary.*

Denver Society of Civil Engineers.

DENVER, COLO., SEPT. 14, 1897.—First regular meeting since the summer vacation called to order in Room 36, Jacobson Building, at 8 P.M., President Wilson in the chair, with several members present. Minutes of special meeting held June 1, 1897, were read and approved. No regular meeting held June 8, as the members of the Society were invited to attend in a body an evening session of the seventeenth annual convention of the American Water Works Association, at their headquarters, Albany Hotel.

After the canvass of the ballots, Messrs. John St. J. Lallie, of Denver, and Edwin H. Messiter, of Leadville, Colo., were declared elected to membership in the Society.

Sundry communications were read and ordered placed on file, the secretary being instructed to make the necessary replies in some cases.

Some of the members present reported having applications from persons desiring admission to the Society. Names to be presented at next meeting.

The librarian reported having found some supposed missing volumes from the library. The same, not being properly indexed, had been misplaced.

A paper, entitled "Colorado, a Sketch," by W. B. Lawson, was read by the secretary (owing to sickness, Mr. Lawson being unable to attend). The paper was a very interesting descriptive history of the State, and was well received by all present.

Mr. H. Breen stated that at the next meeting he would have some calculating machines on exhibition for discussion as to their merits, etc. Adjourned.

WALTER PEARL, *Secretary.*

Association of Engineering Societies.

Vol. XIX. OCTOBER, 1897. No. 4.

PROCEEDINGS.

Engineers' Club of St. Louis.

458th Meeting, October 6, 1897.—The meeting was held at 1600 Lucas Place at 8 p.m., with President Flad in the chair. Nineteen members and five visitors were present.

The minutes of the 457th regular meeting and the 242d meeting of the Executive Committee were read and approved.

A letter was read from Mr. F. B. Maltby, Assistant United States Engineer in charge of the government works on the Osage River, inviting the club to visit the new dam now being built near Osage City. A motion was passed authorizing the Executive Committee to arrange for an excursion to this place.

The secretary announced that he had received applications for membership from Messrs. Wm. A. Hunicke, Vernon Baker, Henry H. Humphrey, George I. Bouton, E. C. Stolberg, Alwin Hofmann and Lee D. Fisher. These applications were referred to the Executive Committee.

The applications of Mr. Henry Branch, assistant engineer with Mr. Edward Flad, and Mr. Charles W. Hawkes, manager of the Springfield Boiler and Manufacturing Company, having been favorably reported upon by the Executive Committee, these gentlemen were balloted for and elected members of the club.

The paper of the evening, entitled "The Electrolysis of Caustic Soda," by Mr. A. L. McRae, was then read. In the absence of Mr. McRae, the paper was read by Mr. Miller. A process of manufacturing caustic soda from common salt by electrolytic methods was described and some figures given as to the cost of manufacture. This process has been used in England and Germany, but is not in use in this country. The paper described how the by-products, hydrogen and chlorine, may be utilized in heating the solution for concentration and in the manufacture of bleaching powder.

Following this paper, there were exhibited a number of lantern slides showing types of waterworks engines and sewage pumps. Mr. M. L. Holman explained the slides and pointed out the features of interest connected with each engine.

There being no further business, the meeting adjourned.

Richard McCulloch, *Secretary.*

459TH MEETING, OCTOBER 20, 1897.—The Club met at 8 P.M., at 1600 Lucas Place, with President Flad in the chair; twenty-four members and four visitors were present.

Before proceeding with its regular business the Club was entertained by the exhibition of a large number of stereopticon views, showing the various kinds of river improvement work used on the Mississippi and Missouri rivers. Views of dikes, levees, wing-dams and devices for protecting the banks of rivers were shown.

Mr. J. A. Ockerson pointed out the features of interest in the different views and explained the uses and methods of construction of the various dikes, levees, dams, etc. This collection of views belongs to Prof. D. L. Turner, of Harvard University, who kindly loaned it to the Club.

The minutes of the 458th meeting of the Club and the minutes of the 243d meeting of the Executive Committee were read and approved.

Messrs. Wm. A. Hunicke, Vernon Baker, Geo. I. Bouton, Henry H. Humphrey, E. C. Stolberg, A. Hoffman and L. D. Fisher were elected members.

Mr. Wm H. Bryan gave a short talk on "The Methods of Testing the Efficiency of a Heating System." He briefly explained the different systems of heating and reviewed the methods of testing heating systems that had been proposed by different writers.

Mr. Wm. Kent, of New York, and Messrs. Flad, Borden, Johnson and Kinealy took part in the discussion which followed.

J. H. KINEALY, *Secretary pro tem.*

Detroit Engineering Society.

DETROIT, MICH., OCTOBER 22, 1897.—The regular monthly meeting was held at the Hotel Ste. Claire, Friday evening, October 22, 1897, Vice-President Dow presiding, and twenty-one members and three visitors present.

The application of Mr. J. W. Schaub for membership by transfer from the Engineers' Club of St. Louis was favorably reported by the Executive Committee and he was elected to resident membership, with remission of initiation fee and of dues until January 1, 1898. The names of Messrs. C. W. Russell and T. F. McCrickett were proposed for membership and referred to the Executive Committee.

The Society then listened to "Some Notes on the Manufacture and Use of Aluminum," by Mr. Jesse M. Smith, which was read by the Secretary, a telegram from Mr. Smith regretting his absence being read by the Chairman. An extended discussion followed, after which the Society adjourned.

GARDNER S. WILLIAMS, *Secretary.*

Civil Engineers' Society of St. Paul.

ST. PAUL, MINN., OCTOBER 4, 1897.—A regular meeting of the Civil Engineers' Society of St. Paul was held at 9 P.M. Present, eight members and one visitor, Mr. Loweth presiding. Mr. C. A. Alderman read a paper on the Chippewa Valley Electric Railway, an up-to-date system of about 22 miles nearly completed. Power is to be furnished for twenty years at $6

per H. P. Mr. Alderman also described the late trip of the Western Society of Engineers to Niagara and the Lehigh Valley, he being the only one of our members to take advantage of the general invitation to participate. The secretary was instructed to again thank the Western Society committee and express the hope that some future excursion of that Society might include a visit to the Twin Cities of the Northwest, where a welcome to many points of interest awaits its members.

Mr. Loweth exhibited the results of some paint tests—twenty-odd samples of black and more or less rust-roughened plates of sheet-iron, which had undergone six months' exposure to locomotive smoke while suspended from the roof of the Union Depot train-shed about 50 feet above the tracks. The iron plates, new and bright, had each received one coat of paint, and had been subjected to equal exposure. The red lead sample gave the best results; next came the white lead, followed by the iron oxides and an asphaltum, which were generally in much better condition than the graphites. An anti-rust specimen was the brownest spectacle of the lot.

C. L. Annan, *Secretary.*

The Civil Engineers' Club of Cleveland.

Case Library Building, Cleveland, O.—The October meeting of the Club was held in Case Library Tuesday evening, the 12th, President Ritchie in the chair. Present, 36 members and 16 visitors. In the absence of Secretary Coburn, W. H. Searles was elected Secretary *pro tem.* The minutes of the last meeting were read and approved. The applications for active membership of Mr. H. E. Andrews and Mr. T. M. Brown were presented and read. Nominations for the office of vice-president, which had been left vacant by the resignation of Mr. Clarence M. Barber, were announced to be in order. Mr. Frank C. Osborn was nominated by Mr. Searles, and on the motion of Prof. John W. Langley the nominations were closed and the Club proceeded to ballot. Messrs. Oldham and Searles were appointed tellers. Mr. Osborn was declared elected by unanimous vote. A paper entitled "The Mechanical Side of Steel Making" was then read by Mr. John MacGeorge. The paper dealt particularly with the latest methods and devices for mechanically charging open-hearth steel furnaces. A number of slides showing recent inventions in this line and the best devices of this kind now in use were cast upon a canvas and graphically described by Mr. MacGeorge. The subsequent discussion was begun by Mr. C. O. Palmer and participated in by Messrs. Johnson, Searles, Oldham, Raynal and Harman.

Wm. H. Searles, *Secretary pro tem.*

Technical Society of the Pacific Coast.

San Francisco, Cal., October 1, 1897.—Regular meeting called to order at 8.30 p.m. by Past President Grunsky.

The minutes of the last regular meeting were read and approved.

Application for membership was made by Hiram R. Jones, chief engineer of the Selby Smelting and Lead Company, proposed by Louis Falkenau, George W. Dickie and Adolph Lietz.

Mr. W. H. Smyth read the paper of the evening, entitled "The His-

tory and Development of Hydraulic Dredging," which was discussed at length by Mr. A. B. Bowers and many members present.

It was moved that the reading of the paper on the subject of "An Old-time Level," announced for this meeting, be postponed until the next regular meeting. Seconded and carried.

Adjourned.

OTTO VON GELDERN, *Secretary.*

Boston Society of Civil Engineers.

BOSTON, MASS., SEPTEMBER 15, 1897.—A regular meeting of the Society was held at Chipman Hall, Tremont Temple, Boston, at 8 o'clock P.M., President Dexter Brackett in the chair; one hundred and five members and visitors present.

The record of the last meeting was read and approved. Mr. Charles W. Hazelton was elected a member of the Society.

The Secretary read a letter from Mr. William B. Fuller resigning the office of Librarian of the Society on account of removal from Boston, and on motion the resignation was accepted. On motion of Mr. French it was voted to appoint a committee of three to report at the next meeting the names of candidates for Librarian. The President appointed as this committee Messrs. A. H. French, C. H. Swan and W. E. Foss.

Mr. Kimball for the committee appointed to prepare a memoir of Horace L. Eaton, submitted its report which was read.

The literary exercises of the evening consisted of an informal address by Mr. F. P. Stearns, describing the work now being built for the Metropolitan Water Supply of Massachusetts. The address was illustrated by a very complete set of lantern slides.

Adjourned.

S. E. TINKHAM, *Secretary.*

OCTOBER 20, 1897.—A regular meeting of the Society was held at Chipman Hall, Tremont Temple, Boston, at 8 o'clock P.M., President Dexter Brackett in the chair; one hundred and nine members and visitors present.

The record of the last meeting was read and approved. Messrs. Edward S. Foster, James W. Martin, Will J. Sando and James L. Tighe were elected members of the Society.

The Treasurer was authorized, with the approval of the President to dispose of the railroad stock owned by the Society.

The committee appointed to nominate a Librarian submitted its report and upon a ballot being taken, Mr. Frank L. Fales was elected Librarian.

The thanks of the Society were voted to the officials of the Boston and Maine and of the Boston and Albany Railroad Companies and to the Metropolitan Water Board, for courtesies extended to the Society on the occasion of the excursion to Clinton on September 25. The thanks of the Society were also voted to the Boston officials of the Boston Terminal Company for courtesies shown the Society this afternoon.

Mr. Thomas H. Wiggin then read a paper, entitled "The Manufacture and Inspection of Cast Iron Pipe." The paper was illustrated by lantern slides.

Adjourned. S. E. TINKHAM, *Secretary.*

Horace Lafayette Eaton.—A Memoir.

By G. A. Kimball, Henry Manley and W. F. Learned, Committee of the Boston Society of Civil Engineers.

[Read September 15, 1897.]

Horace Lafayette Eaton was born in Boston, September 6, 1851. He was educated in its public schools, and entered the employ of the city of Boston in the City Engineer's Department in 1869. Amongst the works with which he was connected for the city of Boston are the High Service supply for South Boston and Dorchester, the Parker Hill reservoir, the Central Avenue bridge at Milton Lower Mills, Malden bridge and the Mystic Valley sewer. From 1884 to 1887 he was connected with the Park department and was engaged upon the Arnold Arboretum, Franklin and other parks.

In 1887 he was appointed City Engineer of Somerville, a position for which his experience of seventeen years in almost every kind of municipal engineering particularly fitted him, and by virtue of his office was Superintendent of Sewers, Engineer to the Water Board, and in charge of all engineering work for the city, including the new High Service System of waterworks, construction of sewers, and the Powder House Park. The latter was a work of art for which he was entitled to, and received, great credit.

Mr. Eaton was thoroughly honest and conscientious in every detail. He was peculiarly sensitive, especially when his plans, which were worked out with the greatest care, were criticised or changes suggested. He felt these suggestions or criticisms keenly, and brooded over them to such an extent as to cause him, sometimes, temporary illness.

In 1895 a few disaffected contractors and others circulated stories detrimental to Mr. Eaton's reputation for honesty, and finally influenced the City Council to order an investigation of his department, which was commenced on November 22. One hearing had been held, his enemies were allowed the greatest latitude in relating stories which were afterward proved false. The publication of these proceedings in the daily papers so worked upon Mr. Eaton's mind that, in a fit of temporary insanity, he took his own life, on November 23, 1895.

After his death, the investigation was continued by the City Council in a most thorough and searching manner. The report completely exonerated Mr. Eaton in every particular and severely censured every person who was in any way connected with the prosecution. The investigation proved that Mr. Eaton was a man of strict integrity, and it is the universal opinion of the citizens of Somerville that he performed his duties faithfully and that he was an honest, upright and painstaking official.

Mr. Eaton joined the Boston Society of Civil Engineers, March, 19, 1879, and served the Society as its secretary from December 20, 1882, to May 18, 1887. His faithful and conscientious service to this Society as its executive officer was thoroughly appreciated and the care and unsparing labor bestowed upon his work for it was characteristic of his whole life. He joined the American Society of Civil Engineers, February 1, 1893. Mr. Eaton leaves a wife and two daughters.

Association of Engineering Societies.

Vol. XIX. NOVEMBER, 1897. No. 5.

PROCEEDINGS.

The Detroit Engineering Society.

Detroit, Mich., November 19, 1897.—The regular monthly meeting was held at the Hotel Ste. Claire, with President Jesse M. Smith presiding and thirty-two members and one visitor present.

Messrs. C. W. Russell and T. F. McCrickett were elected to resident membership.

The name of Mason L. Brown was proposed for membership and referred to the Executive Committee.

A proposed by-law was noticed as follows: "Persons not uniting with this Society within three months of the date of election to membership shall be considered as never having been proposed." Laid over to next regular meeting.

By request, the discussion of the paper on "Aluminum," presented at the last meeting, was continued by Messrs. Mattsson, Weil, Keep, Danzinger, Pettee, Cooley and Smith. The Society then listened to the paper of the evening, by Mr. W. J. Keep, on "Cast-iron under Impact," which was Pettee, Cooley and Smith. The Society then listened to the paper of the evening, by Mr. W. J. Keep, on "Cast-iron under Impact," which was discussed by Messrs. Cooley, Folger, McMath, Weil, Molitor, Smith, Dow and Keep.

A paper for the next meeting, on "Ornamental Marbles," by W. M. Courtis, was announced, after which the Society adjourned.

Gardner S. Williams, *Secretary.*

Detroit, Mich., November 19, 1897.—A meeting of the Executive Committee of the Detroit Engineering Society was held at the Hotel Ste. Claire. Present, Messrs. Smith, Keep, Hinchman, Pope and Williams. The fourth quarterly assessment of the Association of Engineering Societies, amounting to $23.75, was ordered paid. The applications for resident membership of Messrs. C. W. Russell and T. F. McCrickett were endorsed, and it was voted to extend to Alfred Noble, C. E., the invitation of the Society to avail himself of a member's privileges during his engagements in Detroit. Adjourned.

Gardner S. Williams, *Secretary.*

Civil Engineers' Society of St. Paul.

St. Paul, Minn., November 1, 1897.—A regular meeting of the Civil Engineers' Society of St. Paul was held at 8.30 p.m. Present, 7 members. Minutes of previous meeting read. Mr. Woodman, chairman of Committee on Membership, presented a table showing the requirements for membership in various branches of the Association of Engineering Societies, and the committee was requested to report at the next regular meeting recommendations as to membership and name. The Secretary read a paper on "Paint Tests," by Mr. W. J. Wilgus, and a vote of thanks for the same was accorded Mr. Wilgus. President Hilgard then read a few notes on "The Development of Water Powers." At Telluride, Col., a head of 900 feet is utilized, and power is transmitted to the various mining camps a maximum distance of 14 miles. Even at a cost of $120 per horse-power per annum, a saving of 25 per cent. over the old coal methods is claimed, and the electric light appears quite generally in the miner's cabin. Water power is now transmitted 50 miles into Salt Lake City and 20 miles into Butte, with the possibility of greater power being brought in from a distance of 60 miles. Mr. Estabrook spoke of the relative cost of steam and water power at the Minneapolis Mills.

C. L. Annan, *Secretary.*

Conditions of Membership in the Engineering Societies, April, 1897.

	Civil	Me-chan'l	Min-ing	Elec-trical	Mili-tary	Geol-ogists	Archi-tects	Sur-vey'rs	General Interest in Science	Years of Pract. alone	College Degree & Years Practice
Boston	*	*	*	*	*	*	*	*			
Virginia	*	*	*	*		*	*				
Cleveland	*	*	*	*	*	*	*	*	*	3	* and 1
St. Louis	*	*	*	*	*	*			*		
St. Paul	*	*	*			*				5	* and 3
Minneapolis	*	*	*	*	*	*					
Denver	*	*	*	*				*		2	* and 2
Montana	*	*	*		*	*	*		*	5	*
Pacific Coast	*	*	*	*	*		*	*		5	* and 3

* An asterisk indicates that a person of the class indicated by the heading of the column is eligible to membership in the Society whose name appears at the end of the line.

Technical Society of the Pacific Coast.

November 5, 1897.—Regular meeting called to order at 8.30 p.m. by Prof. Frank Soulé.

The minutes of the last regular meeting were read and approved.

The following were elected to membership:

1. Hiram R. Jones, chief engineer of the Selby Smelting Works.
2. P. R. Lamar, chief engineer of the Golden Crown Mining Company.

The Secretary read a paper written by Mr. H. Clay Kellogg, entitled "Pipe Line No. 2, and the Lands Irrigated under the Same at Corona, Riverside County, Cal.," which was discussed.

The Secretary read a paper, entitled "A Level of Ye Olden Time," which was discussed by a paper written and read by Mr. Adolf Lietz.

Adjourned.

Otto von Geldern, *Secretary.*

Engineers' Club of St. Louis.

460th Meeting, November 3, 1897.—The Club met at 8 p.m., at 1600 Lucas Place, with President Flad in the chair. Thirty-three members and three visitors were present.

The minutes of the 459th meeting of the Club and the 244th meeting of the Executive Committee were read and approved.

The President announced that Mr. T. A. Mysenberg had presented to the Club several volumes of *London Engineering.* The thanks of the Club were voted to Mr. Mysenberg for this donation.

The paper of the evening, by Mr. F. F. Harrington, entitled "Underground Conduits in St. Louis," was then read. A short history of the legislation on this subject was given, and the requirements of the final ordinance were set forth. The rules adopted by the Board of Public Improvements in granting permits and the agreements between the different electric lighting companies were given in detail. Then followed a description of the different systems and conduits which have been adopted. A large number of working drawings and specimens of ducts were exhibited. Lantern slides, showing views taken during the construction, were used in explaining the methods adopted.

The discussion which followed the reading of this paper was participated in by Messrs. Wagner, Abbot, Niper, Reber and McCulloch.

There being no further business, the meeting adjourned to another room, where lunch was served.

Richard McCulloch, *Secretary.*

461st Meeting, November 18, 1897.—The Club met at 8 p.m., at 1600 Lucas Place, with President Flad in the chair. Twenty-six members and one visitor were present.

The minutes of the 460th meeting of the Club and the 245th meeting of the Executive Committee were read and approved.

The application for membership of Mr. Ferdinand Schwerdtmann, superintendent of the Wagner Electric Manufacturing Company, having been favorably reported by the Executive Committee, this gentleman was balloted for and elected a member of the Club.

The President stated that Col. E. D. Meier had presented to the library two volumes of the "Transactions of the Institute of Mining Engineers." The thanks of the Club were voted Colonel Meier for this donation.

Mr. J. A. Ockerson made a motion that a nominating committee consisting of Messrs. B. L. Crosby, Wm. Wise, L. P. Butler, W. G. Comber and F. F. Harrington be appointed to select for the Club a list of nominees for the several offices provided for in the Constitution, and to present the same at the next meeting.

Prof. J. B. Johnson then made an address on "The Results of a Recent Investigation of the Relative Strength of Wooden Beams and Columns in Large and Small Sizes." This investigation was conducted at the testing laboratory of Washington University for the Government Forestry Division. The large beams were of selected lumber, and were tested green. They were 18 to 24 feet in length, and were 8 inches by 12 inches in section. Eight small beams, 5 feet long and 4 inches square in cross-section, were made out of each large beam after it was broken. The beams were of oak, white pine, short leaf pine and long leaf pine. Tests were also made on large pine beams, which had been taken out of the Exposition Building after thirteen years of service. The average of these tests showed that the large beams had 92 per cent. of the strength of the small ones, and that the apparent elastic limit in the large beams was 97½ per cent. of that of the small ones.

Large columns showed a strength of 75 per cent. of small columns.

The discussion which followed was participated in by Messrs. Sterne, Kinealy, Borden, Crosby, Russell, Bouton, Flad and Ockerson.

The Executive Committee, having recommended that Prof. Calvin M. Woodward be elected an honorary member, a motion was made that the vote on this candidacy be postponed until next meeting, and that it be announced in the notice of the meeting, that such a vote would be taken. After some discussion this motion was carried.

There being no further business, the meeting adjourned.

RICHARD MCCULLOCH, *Secretary.*

The Civil Engineers' Club of Cleveland.

THE regular meeting of the Club was held in Case Library, on Tuesday evening, November 9, 1897. President Ritchie was in the chair. There were present 48 members and 9 visitors.

The minutes of the last meeting were read and approved.

Ballots were canvassed for the election to active membership of H. E. Andrews and T. M. Brown. Mr. James MacIntyre and Mr. Frank C. Osborn were appointed tellers.

The report of the regular meeting of the Executive Board was read and the application of L. B. Hoit for active membership recommended.

A communication was presented from Benjamin S. Hubbell, Secretary of the Cleveland Architectural Club, containing notice of their second annual exhibition, to be held November 15–27, and inviting the Club to visit the exhibition *en masse*.

It was moved by Mr. Warner that an evening be appointed by the Executive Board on which the Club could make the visit in a body, and that the invitation thereby be accepted and that thanks be rendered to the

Architectural Club for their kindness. Mr. W. H. Searles moved to amend that the Club appoint the evening, and suggested November 18. Mr. Warner thereupon withdrew his motion in favor of the amendment, which was then carried.

The paper of the evening, entitled "Visits to Some Scientific Institutions in Europe," was then presented by Edward W. Morley, Ph.D., LL.D.

The discussion which followed was participated in by Messrs. Warner, Raynal, Oldham, Miller and others.

The tellers reported H. E. Andrews and T. M. Brown as elected to active membership. The meeting adjourned. A light luncheon was served.

W. H. Searles, *Secretary pro tem.*

BRADLEY & POATES, ENGR'S N.Y

ASSOCIATION
OF
ENGINEERING SOCIETIES.

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PROCEEDINGS.

The Montana Society of Civil Engineers.

THE Montana Society of Civil Engineers will hold its annual meeting in Butte, January 8th next. The date and place of the session was decided at the regular meeting of the Society which was held December 11, 1897, in the Merchants' National Bank building, Helena, Mont.

President C. W. Goodale, of Butte, presided at the meeting, which was well attended. The application for membership of Milo S. Ketchum, of Butte, was favorably considered, and the Secretary was instructed to send out the usual letter ballots.

The report of the Nominating Committee, F. L. Sizer, John Heron and E. H. Wilson, was received and approved. The following is the list of candidates selected: James M. Page, of Twin Bridges, President; Maurice S. Parker, of Great Falls, First Vice-President; Forrest J. Smith, of Helena, Second Vice-President; Albert S. Hovey, of Helena, Secretary and Librarian; James S. Keerl, of Helena, Treasurer and member of the Board of Managers of the Association of Engineering Societies, and Edward R. McNeill, of Boulder, Trustee for three years.

The meeting at Butte next month promises to be largely attended. A Committee on Arrangements will be appointed by the President to arrange the details of the coming session.

Civil Engineers' Club of Cleveland.

CLEVELAND, DECEMBER, 14, 1897.—The regular meeting of the Club was held in Case Library on Tuesday, December 14, at 7.45 P.M., President Ritchie in the chair. Present, forty-two members and ten visitors.

The minutes of the last meeting were read and approved.

The President appointed Messrs. L. Herman and A. A. Skeels tellers to canvass ballots, and on receiving their report in due form he declared Lehman Benjamin Hoit elected an active member of the Club.

The report of the Executive Board referred briefly to the death of Forrest A. Coburn, late Secretary of the Club, which occurred on December 1st inst., and recommended that suitable action be taken thereon.

The Board reported favorably upon the application of Stanley R. Greene for active membership, and his application was read by the Secretary.

The letter of resignation of Cecil L. Saunders, active member, was reported received. The Board would act upon this at its next session.

The Secretary announced the receipt of the following books and papers: Vol. XVIII of the Transactions of the American Society of Mechanical Engineers, from their Secretary, Prof. F. R. Hutton, of New York, a valuable contribution to our library; six numbers of "Water Supply and Irrigation Papers," 5-11, of the United States Geological Survey, from Mr. F. H. Newell, Washington, D. C., and the presidential address of Prof. Mansfield Merriman before the Society for Promotion of Engineering Education, August 20, 1896; also a paper by the same author, on Probability of Hit when Probable Error of Aim is Known, in Artillery Practice."

The President appointed J. R. Richardson, C. W. Hopkinson and Jos. C. B. Beardsley a committee to prepare suitable resolutions upon the death of Mr. Coburn.

The President gave notice that, the office of Secretary being vacant, an election by ballot would be held at the next regular meeting to fill said vacancy for the unexpired term, and that nominations were now in order.

Mr. Osborn nominated W. H. Searles. This was seconded by Mr. Oldham, and there were no other nominations made.

The Secretary announced that, in accordance with the calendar of the Club, there would be a semi-monthly meeting on the 28th of December, at which time a paper by Mr. C. G. Force was expected. Mr. Porter, for the Program Committee, begged leave to state that, as Mr. Force would not be able to have his paper ready by that date, Mr. Newman would present his paper, postponed from the 9th of November last.

The Club then listened to the paper of the evening, on "Boilers," by Mr. John P. Johnston, active member. The author compared various types of boilers as adapted to different purposes, treated of boiler specifications, of the use and abuse of boilers in practice and of their possibilities in the future.

An animated discussion ensued, which was participated in by Messrs. Raynal, Oldham, Newman, Benjamin and Johnston. By invitation, Mr. C. A. Burwell addressed the Club on the same topic.

On motion, the President was empowered to sign the records of previous meetings left unsigned by Secretary Coburn.

The Club adjourned at 9.30 to partake of a light luncheon.

Wm. H. Searles, *Secretary pro tem.*

Cleveland, December 28, 1897.—Special meeting held in Case Library.

The meeting was called to order at 8 o'clock p.m.; President Ritchie in the chair; present, thirty-five members and six visitors.

Minutes of the last meeting were read and approved.

The letter of resignation of Mr. Wm. C. Jewett as Director, on account of his removal from town, was read, and, on motion, his resignation was accepted. Nominations for Director, to fill the vacancy, being in order, Mr. Coffin nominated Mr. Joseph R. Oldham; Mr. Gobeille nominated

Mr. August A. Honsberg, and the nominations were closed. Ballots to be canvassed at the next regular meeting.

The paper of the evening, on "Construction of Ships for Service on the Great Lakes," was then read by Mr. Richard L. Newman, active member.

The paper was illustrated by numerous drawings and charts, and treated of the methods by which modern ships are given greater strength in cross-section without increasing the weight or depth, thus permitting the design of vessels of much greater length and tonnage than were thought possible a few years ago. The proper location of the machinery, as affecting the strength of the hull, was considered.

The discussion was by Messrs. Oldham, Raynal, Cowles, Johnston and Ritchie, members of the Club, and by Capt. John F. Tuttle and Mr. John W. Seaver, visitors. Adjourned. A light luncheon was served.

WM. H. SEARLES, *Secretary pro tem.*

Boston Society of Civil Engineers.

NOVEMBER 17, 1897.—A regular meeting of the Society was held at Chipman Hall, Tremont Temple, Boston, at 8 o'clock, P.M.; President Dexter Brackett in the chair, 127 members and visitors present.

The record of the last meeting was read and approved.

Messrs. Thomas S. Burr, Edward F. Miller and Charles G. Waitt were elected members of the Society.

The President announced the death of Thomas Doane, a past president of the Society, which occurred on October 22, 1897, and, on motion, the President was requested to appoint a committee to prepare a memoir. The committee appointed consists of Messrs. Desmond Fitzgerald, C. Frank Allen and Charles A. Pearson.

The thanks of the Society were voted to the Boston Transit Commission for courtesies extended this afternoon, on the occasion of the visit to the subway.

Mr. Frank A. Barbour then read the paper of the evening, entitled "The Strength of Sewer Pipe and the Actual Earth Pressure in the Trench." The paper was very fully discussed by Messrs. F. H. Snow, T. H. Barnes, Henry Manley and F. C. Coffin, of the Society, and by Messrs. J. A. Baldwin and B. W. Robinson, of Akron, Ohio; E. W. Buel, of the Barberton, Ohio; E. B. Winslow, of Portland, Me.; G. C. Dunn, of Boston, and H. P. Eddy, of Worcester, Mass. Adjourned.

S. E. TINKHAM, *Secretary.*

DECEMBER 15, 1897.—A regular meeting of the Society was held at Chipman Hall, Tremont Temple, Boston, at 8 o'clock P.M.; Vice-President C. Frank Allen in the chair, 82 members and visitors present.

The record of the last meeting was read and approved.

The death of William C. Hall, a member of the Society, was announced, and the President was requested to appoint a committee to prepare a memoir. The President has named as members of that committee Messrs. N. S. Biock, B. T. Wheeler and J. L. Woodfall.

Mr. Frank P. McKibben was then introduced, and read a paper, entitled "The Erection of Metallic Bridges." The paper was very fully illustrated by lantern slides. The discussion which followed the reading of the paper was participated in by Messrs. J. P. Snow, B. W. Guppy, H. J. Howe and H. K. Higgins. Adjourned.

S. E. TINKHAM, *Secretary.*

Engineers' Club of St. Louis.

463D MEETING, DECEMBER 15, 1897.—The annual dinner was held at the Southern Hotel at 8.30 P.M. After the dinner had been served, the meeting was called to order by President Flad. There were thirty-nine members and six visitors present. The President announced that the result of the letter ballot for officers for 1898 was as follows: President, Wm. H. Bryan; Vice-President, B. H. Colby; Secretary, Richard McCulloch; Treasurer, Thos. B. McMath; Librarian, E. J. Jolley; Directors, Edward Flad, John A. Laird. Members of the Board of Managers of the Association of Engineering Societies, J. B. Johnson, Arthur Thatcher.

The proposed amendment to the constitution had been carried by a vote of 91 for the amendment and 8 against it.

President Flad then addressed the Club, giving a *résumé* of the work of the year. He then introduced the new President, Mr. Wm. H. Brvan, who presided during the remainder of the evening. Mr. Bryan made an address in taking the chair, in which he outlined some of the plans for the next year.

Col. E. D. Meier then responded to the toast, "The Engineer Socially Considered." He gave a humorous account of the origin of engineers and engineering, and advised engineers to devote more attention to the social side of life.

Mr. M. L. Holman responded to the toast, "Wanderings Abroad." He gave an account of a recent trip to Germany, his remarks being replete with humor and wisdom.

The toast of "Early Experiences" was responded to by Mr. Henry Branch. The ups and downs of the young engineer were the subject of his remarks.

Mr. F. A. Abbot then addressed the Club on the subject of "The Engineer as a Contractor." After remarking on the universal suspicion which seems to attach itself to the contractor, he prophesied the approach of a golden age, when all contractors would be engineers, and all extra work bills would be paid without question.

Informal remarks were then made by Prof. J. B. Johnson and Prof. C. M. Woodward, after which the meeting adjourned.

RICHARD MCCULLOCH, *Secretary.*

The Detroit Engineering Society.

DETROIT, MICH., DECEMBER 16, 1897.—The regular monthly meeting was held at the Hotel Ste. Claire, President Jesse M. Smith presiding, and thirty-five members and thirteen visitors present.

The paper of the evening was presented by Wm. M. Folger, Commander United States Navy, member American Society Mechanical Engineers,

on "American Armor for Vessels of War," and was extensively illustrated by photographs of results of armor tests. The paper elicited many questions from members, which were extensively considered by the author. The discussion was participated in by Messrs. Dunlap, Wilkes, Smith, Courtis, McMath, Field, Schaub, Williams and Dow.

The application of Mason L. Brown having been reported upon favorably by the Executive Committee, he was elected to resident membership

An invitation was received from the Michigan Engineering Society to participate in the annual convention at Port Huron, December 28 to 30, 1897, and the Secretary instructed to extend the thanks of the Society for the courtesies. Four candidates were proposed for resident membership, and referred to the Executive Committee. The following, to be known as By-Law IV, was adopted:

"Persons proposed for membership who do not unite with the Society within six months of their election, shall be considered as never having been proposed, provided they shall be notified in writing of this By-Law at least thirty days before the termination of this period."

Adjourned.

GARDNER S. WILLIAMS, *Secretary*.

MEETING of the Executive Committee held December 16, 1897. Four members present. Bills amounting to $12.70 for printing, Journals and postage were audited and ordered paid.

Application for membership and By-Law referred to committee at last meeting of the Society were approved and ordered reported.

Checks of form suited to the requirements of the constitution were ordered printed. The following was adopted:

Resolved, That all bills audited by this committee shall be endorsed by the chairman of the meeting at which they are audited.

Adjourned.

GARDNER S. WILLIAMS, *Secretary*.